Maximum Utilization of Energy Source Minerals Using Mineral Processing Techniques: A Review

M.A. AbdelKhalek

Mineral Processing Dept., Central Metallurgical Research & Development Institute (CMRDI), Egypt

A R T I C L E   I N F O

A B S T R A C T

The mineral is one of the most important energy resources. Indirect energy derived from Sun as Biomass. Organic byproducts were converted to fossil fuels through photosynthesis on Earth. Coal is a sedimentary rock that contains the accumulation of organic matter from plants. Coal is upgraded using gravity and flotation techniques. In many countries, SO_2 is being removed from flue gases by different methods. Oil shale is shale that contains organic matter of incomplete conversion to oil. Oil shale can be burned directly to generate electricity. It can be upgraded to increase its organic content. It can be converted to oil or gas through pyrolysis. Nuclear fuel is a material that contains fissionable elements such as Uranium, Plutonium, and Thorium. Uranium is widely distributed in mineral ores. Natural uranium contains 0.7% U235 (fissile isotope) and 99.3% U238. The U235 must be increased up to 8% to be a fuel for energy reactor while the weapon-grade must contain at least 90% U235.

1. Introduction

Clean and inexpensive energy is a challenge. New sources of energy are changing the landscape, products made from fossil fuels, heat our homes, and fuel our cars.

Wind, solar, and bio-fuels as new energy sources may change the lifestyle. Effective transportation to big cities and storage are important requirements for them. Another source of future energy is natural gas. Among the alternatives being considered is equipping vehicles with the ability to consume natural gas. It is important to develop electric cars to offset the demand for gasoline and diesel fuel. Another technology is the hydrogen cars that burn hydrogen. The major advantage of this technology is that the only waste product is water.

A mineral is any substance that comes from Earth. Figure 1 presents a classification of mineral ores. Minerals are sources of metals and nonmetals such as silicon, phosphorus, sulfur. Some minerals are used in their natural form such as clay.

Energy Resources are classified into:

- Conventional (wood, coal, oil, natural gas, and electricity).
- Non-conventional (wind, solar, biogas, and atomic energy).

There are two essential energy sources on Earth are:
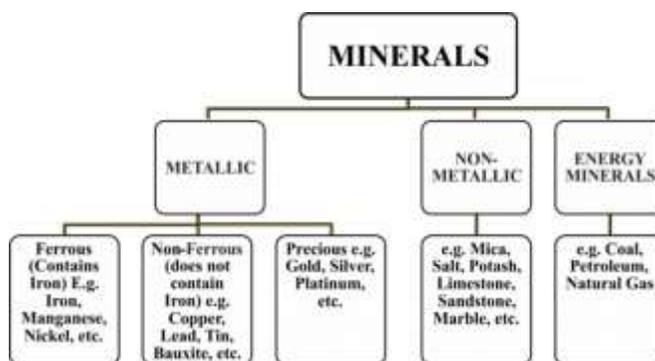
**Figure1: Classification of Mineral Ores**

- Solar Energy: Electromagnetic radiation from Sun.
- Nuclear Energy: Radioactive decay of atoms.

Energy derived directly from Sun is used in heating and generates electricity by solar cells or indirectly biomass energy produced

*M.A. AbdelKhalek, Central Metallurgical Research & Development Institute (CMRDI), Egypt, +201014113824&kalekma@yahoo.com

by photosynthesis. Biomass energy is stored on Earth as fossil fuels.

As atomic fission enormous energy is released as heat which is used for electric generation. But nuclear power is not considered as a safe, cheap, and clean source [1].

Metallic and non-metallic industries are the most sources of greenhouse emissions and consume huge amounts of energy. Only 10 countries consumed more than 80% of the world's energy and emissions releasing [2].

Biofuels can be used in the steel industry rather than coke with some limit (max60%) due to blast furnace technology. Although hydrogen is an energy source, it has limited applicability in steel and non-ferrous metals industries.

Although electricity is theoretically easier to be replaced by renewable energy sources, the hydropower potential may be a promising energy source for many countries as a stable electricity supply and to reduce emissions from electricity in the minerals industry [2].

2. Energy Source Minerals

2.1. Fossil Fuels

Fossil fuel is formed because of the rapid burial of organic matter on Earth. It is converted to hydrocarbons through a series of slow chemical reactions. Hydrocarbons are chains of carbon and hydrogen elements. Oil and natural gas consist of numerous different hydrocarbons, but the most important of them are the paraffin group (C_nH_{2n+2}).

Oil shale is shale that contains un-decomposed organic matter or intermediate to be oil. Oil can be extracted from oil shale through pyrolysis. It must be heated to drive the oil out. This process requires much energy, so it is not cost-effective. It may become so with the depletion of petroleum. Tar sands are sandstones that include oil in their pores. The extraction of this oil is energy-intensive because it requires heating.

Coal is a sedimentary or metamorphic rock. It is produced because of the accumulation of organic matter from plants. Water and methane were derived off from peat because of compaction, producing lignite. It is black-colored organic-rich coal. Further compaction and heating form bituminous coal. Anthracite is produced if rock becomes metamorphosed. Carbon is converted to graphite under extremely higher temperatures and pressure. It is not useful as an energy source because it burns only at high temperatures. Anthracite coal produces more energy compared with bituminous and lignite, [3].

2.2. Nuclear Energy Fuels:

Nuclear fuel must include heavy fissionable metals. Nuclear fuel is shaping as rods of fuel material, mixed with neutron reflecting materials. Uranium-235 (^{235}U), Plutonium-239 (^{239}Pu) and Thorium-232 (^{232}Th) are the most common fuels.

Small amounts of nuclear power can be used as a result of the radioactivity of Plutonium-238 and some other elements. In a nuclear fusion reactor, light nuclides such as tritium (^3H) are used as fuel. In fission reactors, fuel oxides are used rather than

metal because the oxide melting point is much higher than its metal and it is not burnable (it is already in the oxidized state) [4, 5]. Several nuclear reactors used Thorium as a fuel [6].

3. Occurrence, Reserves, and Production of Energy Source Minerals

3.1. Fossil Fuels

3.1.1. Coal

Coal is a black sedimentary rock, the harder coal is anthracite coal. It is a metamorphic rock because of its exposure to elevated temperature and pressure, [7].

Coal is derived from dead plant matter and peat matter which is converted into lignite, then sub-bituminous coal, bituminous coal, and lastly anthracite. It involves many biological and geological processes that took place over a long period [8]. Lignite is the lowest coal grade. It is a brown color with high moisture content.

Bituminous coal is found at very deep and it is the most commercially used and widespread coal. Its High grade is the best metallurgical application. Anthracite is the higher hard coal quality [1].

Energy Information Administration (EIA) estimated that there are 861 billion tons as proved recoverable coal. They are equivalent to 4,106 Billion of oil Barrels, Table 1 [8].

The United States has coal resources higher than the natural gas and oil resources, based on total British thermal units (Btu). In the period between 1990 and 1999, EIA obtained updated coal reserves information and data largely through its Coal Reserves Database (CRDB) program. According to that, the revised coal reserves estimates include improved analyses of coal quality, recoverability, and accessibility in the studied areas.

It is important to state that the recovery rates vary greatly between underground and surface mining. The coal resources that can be recovered from deposits varies from less than 40% in some underground mines to more than 90% at some other surface mines. Adverse geologic features in a mining area, such as folding, faulting, and inter-layered rock can limit the amount of recovered coal. The property rights, land-use conflicts, and environmental restrictions showed that there is only 53% of the DRB may be available or accessible for mining.

Annually, EIA estimates the recoverable coal reserves by adjusting the DRB to reflect both accessibility and recovery rates in mining. In 2018, EIA estimated that the remaining U.S. recoverable coal reserves are more than 253 billion tons, from a DRB of 475 billion tons.

The United States has a higher coal reserve of 237.2 billion ton (22.6%), Russia has 157 billion ton (14.4%), China has 114 billion ton (12.6%), Australia has 76 billion ton (8.9%) and India has 60.6 billion ton (7%). In 2007, Petroleum estimated those 147 years of reserves-to-production. It is based on proven coal reserves worldwide [10].

Table 1: Recoverable coal reserves (million tons) [12, 13].

Country	Anthracite & Bituminous	Sub-Bituminous	Lignite	Total	Percentage of World Total
USA	108,501	98,618	30,176	237,295	22.6
Russia	49,088	97,472	10,450	157,010	14.4
China	62,200	33,700	18,600	114,500	12.6
Australia	37,100	2,100	37,200	76,400	8.9
India	56,100	0	4,500	60,600	7.0
Germany	99	0	40,600	40,699	4.7
Ukraine	15,351	16,577	1,945	33,873	3.9
Kazakhstan	21,500	0	12,100	33,600	3.9
S.Africa	30,156	0	0	30,156	3.5
Serbia	9	361	13,400	13,770	1.6
Colombia	6,366	380	0	6,746	0.8
Canada	3,474	872	2,236	6,528	0.8
Poland	4,338	0	1,371	5,709	0.7
Indonesia	1,520	2,904	1,105	5,529	0.6
Brazil	0	4,559	0	4,559	0.5
Greece	0	0	3,020	3,020	0.4
Bos.&Herz.	484	0	2,369	2,853	0.3
Mongolia	1,170	0	1,350	2,520	0.3
Bulgaria	2	190	2,174	2,366	0.3
Pakistan	0	166	1,904	2,070	0.3
Turkey	529	0	1,814	2,343	0.3
Uzbekistan	47	0	1,853	1,900	0.2
Hungary	13	439	1,208	1,660	0.2
Thailand	0	0	1,239	1,239	0.1
Mexico	860	300	51	1,211	0.1
Iran	1,203	0	0	1,203	0.1
Czech Rep.	192	0	908	1,100	0.1
Kyrgyzstan	0	0	812	812	0.1
Albania	0	0	794	794	0.1
N.Korea	300	300	0	600	0.1
N.Zealand	33	205	333-7000	571	0.1
Spain	200	300	30	530	0.1
Laos	4	0	499	503	0.1
Zimbabwe	502	0	0	502	0.1
Argentina	0	0	500	500	0.1
All others	3,421	1,346	846	5,613	0.7
World Total	404,762	260,789	195,387	860,938	100

Table 2 shows the world production of coal. In 2011, the production by China was 3,520 M tons (it is approximately 50% of world coal production). The United States (993 Mt), India (589 Mt), European Union (576 Mt), and Australia (416 Mt) [11]. Table 3 shows the world consumption of coal, [12].

Table 2: Coal Production by Country (million tons) [10].

Country	2004	2005	2006	2007	2008	2009	2010	2011	Share	Reserve (years)
China	2122	2349	2528	2691	2802	2973	3235	3520	49.5%	35
U.S.A.	1008	1026	1054	1040	1063	975	983	992	14.1%	239
India	407	428	449	478	515	556	573	588	5.6%	103
Euro.Un.	627	607	595	592	563	538	535	576	4.2%	97
Australia	364	375	382	392	399	413	424	415	5.8%	184
Russia	281	298	309	313	328	301	321	333	4.0%	471
Indonesia	132	152	193	216	240	256	275	324	5.1%	17
S.Africa	243	244	244	247	252	250	254	255	3.6%	118
Germany	207	202	197	201	192	183	182	188	1.1%	216
Poland	162	159	156	145	144	135	133	139	1.4%	41
Kazakh.	86	86	96	97	111	100	110	115	1.5%	290
World Total	5,716	6,035	6,342	6,573	6,795	6,880	7,254	7,695	100%	112

Table 3: Coal Consumption by Country (million tons) [11].

Country	2008	2009	2010	2011	Share
China	2,966	3,188	3,695	4,053	50.7%
USA	1,121	997	1,048	1,003	12.5%
India	641	705	722	788	9.9%
Russia	250	204	256	262	3.3%
Germany	268	248	256	256	3.3%
S. Africa	215	204	206	210	2.6%
Japan	204	181	206	202	2.5%
Poland	149	151	149	162	2.0%
World Total	7,327	7,318	7,994	N/A	100%

Table 4 shows the major exporters. The largest exporters are Australia (328.1 Mt), Indonesia (316.2 Mt), and Russia (122.1 Mt). Table 5 shows the major importers. The largest importers are Japan (206.7 Mt), China (195.1 Mt), and South Korea (125.8 Mt) [13-17].

Coal Specifications: Bituminous coal is commonly called steam coal or thermal coal which is used in power and heat generation [18-20]. Specification of steam coal is about 5000 Kcal/kg, total moisture ≤ 24%, Inherent Moisture ≤ 12%, Ash ≤ 10%, and total sulfur ≤ 1% [21, 22].

Egypt has a small underground coal mine in the Sinai Peninsula. Although its production is 0.36 Mt/y of non-coking coal and the national demand is 1.2 Mt/y, it is blended with imported

metallurgical coal. The recoverable amount is 17.637 million tons [23].

Table 4: Coal Exports by Country (million tons) [15-17].

Country	2004	2005	2006	2007	2008	2009	2010	Share
Australia	247.6	255.0	255.0	268.5	278.0	288.5	328.1	27.1%
Indonesia	131.4	142.0	192.2	221.9	228.2	261.4	316.2	26.1%
Russia	55.7	98.6	103.4	112.2	115.4	130.9	122.1	10.1%
USA	48.0	51.7	51.2	60.6	83.5	60.4	83.2	6.9%
S.Africa	74.9	78.8	75.8	72.6	68.2	73.8	76.7	6.3%
Colombia	56.4	59.2	68.3	74.5	74.7	75.7	76.4	6.3%
Canada	28.8	31.2	31.2	33.4	36.5	31.9	36.9	3.0%
Kazakh.	27.4	28.3	30.5	32.8	47.6	33.0	36.3	3.0%
Vietnam	11.7	19.8	23.5	35.1	21.3	28.2	24.7	2.0%
China	95.5	93.1	85.6	75.4	68.8	25.2	22.7	1.9%
Mongolia	1.7	2.3	2.5	3.4	4.4	7.7	18.3	1.5%
Poland	27.5	26.5	25.4	20.1	16.1	14.6	18.1	1.5%
Total	764.0	936.0	1,000.6	1,073.4	1,087.3	1,090.8	1,212.8	100%

Table 5: Coal Imports by Country (million tons) [14, 18].

Country	2006	2007	2008	2009	2010	Share
Japan	199.7	209.0	206.0	182.1	206.7	17.5%
China	42.0	56.2	44.5	151.9	195.1	16.6%
S. Korea	84.1	94.1	107.1	109.9	125.8	10.7%
India	52.7	29.6	70.9	76.7	101.6	8.6%
Taiwan	69.1	72.5	70.9	64.6	71.1	6.0%
Germany	50.6	56.2	55.7	45.9	55.1	4.7%
Turkey	22.9	25.8	21.7	22.7	30.0	2.5%
UK	56.8	48.9	49.2	42.2	29.3	2.5%
Italy	27.9	28.0	27.9	20.9	23.7	1.9%
N. lands	25.7	29.3	23.5	22.1	22.8	1.9%
Russia	28.8	26.3	34.6	26.8	21.8	1.9%
France	24.1	22.1	24.9	18.3	20.8	1.8%
USA	40.3	38.8	37.8	23.1	20.6	1.8%
Total	991.8	1,056.5	1,063.2	1,039.8	1,178.1	100%

3.1.2. Oil Shale

The main organic matter in oil shale is kerogen (insoluble in organic solvents), and bitumen (soluble in organic solvents). In the absence of migrant hydrocarbons, kerogen is usually 95% [24]. Bitumen is a molecular organic matter. It is saturated; aromatic and polar compounds-resins and asphalt [25] while kerogen is composed of particulate organic matter with empirical formula $C_{421}H_{638}O_{44}S_4NCl$, Figure 2 [26]. The economy of reserves depends on its kerogen content and extraction costs. It also depends on the oil price.
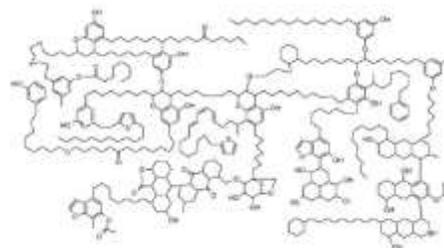
Fig.2: Chemical structure of kerogen with empirical formula $C_{421}H_{638}O_{44}S_4NCl$ [27]

Oil shale deposits are widespread over the world. But most of them cannot explore economically. There are 600 known oil shale deposits [27]. Well-explored deposits could be classified as reserves. Expected deposits at Green River (USA), Queensland-Australia, Sweden, Estonia, Jordan, France, Germany, Brazil, China, and Russia would yield 40 liters of oil per ton[28, 29].

In 2008, 689 giga-tons are the total world resources. It is equivalent to 4.8 trillion barrels of oil (760 billion meters). The largest reserve is 3.7 trillion barrels in the United States (590 billion meters). Conventional oil reserves are estimated to be 1.317 trillion barrels [30].

Estimating shale oil reserves is complicated. Some reserves are estimated as the kerogen in place. These estimates do not consider extracted kerogen. Most definitions refer only to the technically exploitable amounts and economically feasible. Extraction technologies are still developing, so the amount of recoverable kerogen can only be estimated [27-31].

Table 6 shows the major African deposits. They are located in Congo (14.3 bmt) and Morocco (6.4 bmt). Deposits in Congo are not properly explored yet [29]. In Morocco, only limited program research has been studied [32]. South Africa, Egypt, Madagascar, and Nigeria have oil shale reserves [29]. China has a major Asian deposit [30-34].

In Europe, the reserves are located in Russia (35 bmt), Italy(10 bmt), Estonia (2.5 bmt), France (1 bmt) and Belarus (1 bmt) [29]. Jordan has high-quality deposits (5.2 bmt) except its high sulfur content [30-35]. The United States has the largest deposit (Devonian-Mississippian, Colorado, Wyoming, and Utah).
Resource in Australia is estimated at 4.5 bmt. Brazil has the second resources and it is the second producer, Table 7 [35, 36].

Egyptian reserves at Eastern and the Western Desert are estimated at 4.5 and 1.2 mt [37]. In 1996 Phoenix Resources, of Qarun Lake was discovered [38]. Apache has developed 18% of 10 million acres. About 50 exploration wells and plans included development and exploration [39, 40].

Table 6: Largest oil shale deposits by John Dyni [30].

Deposit	Country	Oil shale resources million barrels	million tons
Green River Formation	United States	1,466,000	213,000
Phosphoria Formation	United States	250,000	35,775
Eastern Devonian	United States	189,000	27,000
Heath Formation	United States	180,000	25,578
Olenyok Basin	Russia	167,715	24,000
Congo	Congo	100,000	14,310
Irati Formation	Brazil	80,000	11,448
Sicily	Italy	63,000	9,015
Tarfaya	Morocco	42,145	6,448
Volga Basin	Russia	31,447	4,500
Baltic Oil Shale Basin	Russia	25,157	3,600
Vychegodsk Basin	Russia	19,580	2,800
WadiMaghar	Jordan	14,009	2,149
Graptolitic argillite	Estonia	12,386	1,900
Timahdit	Morocco	11,236	1,719
Collingwood Shale	Canada	12,300	1,717
Italy	Italy	10,000	1,431

Table 7: Oil shale resources and production by regions.

Region	Oil shale resources (10^6 barrels)	Oil shale resources (10^6 tons)	Production in 2008 (10^3 tons)
Africa	159,243	23,317	-
Congo	100,000	14,310	-
Morocco	53,381	8,167	-
Asia	384,430	51,872	375
China	354,000	47,600	375
Europe	368,156	52,845	355
Russia	247,883	35,470	-
Italy	73,000	10,446	-
Estonia	16,286	2,494	355
Mid. East	38,172	5,792	-
Jordan	34,172	5,242	-
N.America	3,722,066	539,123	-
USA	3,706,228	536,931	-
Canada	15,241	2,192	-
Oceania	31,748	4,534	-
Australia	31,729	4,531	-
S.America	82,421	11,794	157
Brazil	82,000	11,734	159
World total	4,786,131	689,227	930

3.2. Nuclear Energy Source Minerals

Uranium is occurring in Earth's crust with abundant, but it is 40 times as silver. To make nuclear fuel, it must be extracted then concentrated in uranium-235 isotope [41]. Although there are hundreds of uranium-containing minerals only a few of them are feasible. Uraninite (uranium dioxide) and pitchblende are the common ores [42]. 5.5 M tons of uranium can be extracted economically (US$59 per lb [43]. 35 million tons are classed as mineral resources [44]. In 2003 the price was $10/lb while in 2007 it is increased to $138/lb. Thus, US$200 million was spent on exploration. Australia has 31% of ore reserves [45] at the Olympic Dam Mine, [46]. Japanese could extract uranium from seawater using ion exchangers feasibly. 4.6 bt uranium is estimated in seawater [47, 48].

In 2005, about 50% of the world's production was produced by Canada and Australia. While more than 30% was produced by Kazakhstan, Russia, Namibia, and Niger [49]. The available uranium is sufficient for at least the next 85 years [44]. Uranium is discovered in high concentrations in Egypt such as in Sinai, Red Sea, Upper Egypt, and the Guitar area, near Hurghada, [50].

Plutonium has twenty radioactive isotopes range from 228 to 247. The half-life of isotope-244 is 80.8 million years so; it is the longest life [51]. There is a small trace of plutonium-239 which decays products as the natural nuclear fission reactor [52, 53].

Thorium is detected in trace amounts in many rocks and soils. Its abundance is triple of tin in the earth crust [54]. The average thorium content in soil is about 6 ppm [55]. Some rare earth mineral ores contain higher thorium content. Thorianite contains 12% as oxide. Monazite, allanite, and zircon have up to 2.5% [56]. Thorium of different isotopes especially Th-232 are present in the Earth's crust exceeds uranium [57-60].

Thorium and other rare earth elements were found in black sands. In the case of the rapid cooling of lava with water, it forms small particles of different sizes. Much of them are of a sand size to be considered sand. Flowing of large lava into an ocean may build a new black sand beach. The lifetime of a black sand beach is short because it is not renewable. It may be disappeared by washing or storms, [61].

4. Mineral Processing Techniques for Energy Source Minerals

4.1. Coal Cleaning

Usually, coal is ground to fine size for beneficiation processes. After that, clean coal is agglomerated. The product is used for power generation. It is burned in a furnace that converts boiler water to steam. It is then used to spin turbines for turning generators. The process efficiency maybe about 35%.More than 40% of the world's electricity is produced by coal, [62, 63].

In 2012, about 30% of the electricity is produced by coal in the United States. It was about 49% in 2008. In 2012, coal is replaced partially by natural gas in the United States. This is due to the low prices of natural gas obtained by hydraulic fracturing of tight shale formations,[64].

Coke is a solid carbonaceous residue. It is formed because of heating low ash and sulfur bituminous coal. The Heating of coal in the absence of air is causing driven off the volatile

constituents away. The fixed carbon and residual mineral matter are fused in each other at a temperature of about 1000°C. Metallurgical coke is used as a fuel and in the iron industry as a reducing agent[65].Petroleum coke is a residue of oil refining, but it is not suitable for metallurgical applications. It has a lot of impurities. Syngas is composed of a mixture of carbon monoxide and hydrogen gases. It is produced as coal gasification [66].

Phosphorus is an important factor in coal grade and its marketing. This is because phosphorus is retained in resultant coke [67]. Thus, it will go into produced iron and subsequently to a steel product. Phosphorus forms super-heater deposits in some boilers [68] and it causes catalysts to poison [69]. Phosphorus has a significant effect on the leaching of coal waste products such as washer refuse and flies ash [70]. Usually, coal has an average phosphorus content of 0.05% [71]. It is approximately equal to phosphorus content in sedimentary rocks (0.042%) [72]. It is stated that the phosphorus is associated with low density (organic) fraction [73, 74].

Refined coal is the product of coal-cleaning technology. In which moisture and certain pollutants were removed from low-rank coal. It is a pre-combustion treatment and process for coal. The technology of pre-combustion coal aims to enhance efficiency and reduce emissions accompanied by coal burning.

4.1.1. Gravity separation technique

Static Separators are based on the separation of particles depending on their differences in specific gravity. The coal is fed into magnetite suspension of required specific gravity which separates the feed into floats (lighter than the media density) and sinks (heavier than the media density). Generally, the particle size of coal feed (range from –75 mm to + 6 mm) is acceptable. Dynamic Separators are based on moving media to impart separation. Heavy media cyclone is the most important example of dynamic separators. It is operated with media range from 1.45 to 1.60 depending on coal quality. Generally, it is suitable for the fraction size of –40 mm to +0.5 mm [75].

Segregation of fine particles in a vibrated gas-fluidized bed can separate fine coal particles from their gangues. Thus, it can skip the problem of fine coal separation in a dry process. It is greatly useful with fine coal for energy resources in North-West China. In this process, jigging is made using gas bubbles for space and time suitable for the segregation of coal particles in the axial direction. It is depending on their hindered settling velocity differences. The fine coal separation with a vibrated gas-fluidized bed system is more effective for fine coal cleaning in cold regions [76].

Usually, fine coals are treated using the flotation technique in most coal preparation plants. Gravity concentration is preferred over flotation if it is feasible. Enhanced gravity separation is established as a promising separator for fine coal, such as Kelsey centrifugal, nelson, and falcon separators, Figure 3 [77].
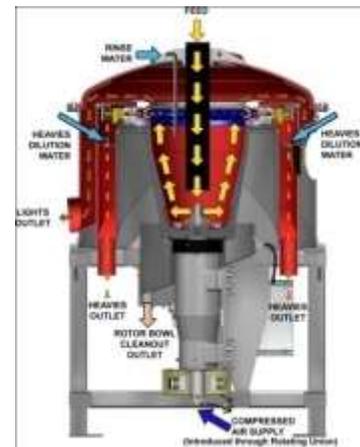

Figure 3: Falcon Concentrator-Enhanced Gravity Separator

The heavy medium can be applied in the enhanced gravity concentrator. It provides separation performances for fine coal that are equal to those achieved for coarse coal. Probable error values were achieved from the treatment of 1000×44 μm coal using magnetite as a heavy medium in a Falcon Concentrator. Their values are typical of that achieved on coarse coal separation by dense-medium cyclones. With a low-density medium of 1.42, the separation was achieved by a heavy medium in Falcon Concentrator. The ash content of difficult-to-clean coal is reduced from 29.0% to about 6.9%.

By using water as a medium in Falcon concentrator, it provides relatively low separation efficiency. The performances of heavy medium separation are great compared to those obtained from modified release analyses. Further evidence is that the gravity-based separation process provides more selective separation than froth flotation systems. The slow particle kinetics can be overcome by the application of an enhanced gravity field [78].

Summarizing the previous works led to the model is extended to cover a wide range of operating conditions and particle properties. The studies available in the literature show good agreement between model predictions and industrial data. Thus, this model can be used to identify separation efficiency limitations. It can provide possible solutions to overcome them. This model can introduce valuable information for improving physical separation processes using a Falcon concentrator, or to evaluate a new application for Falcon separator [79]. Enhanced gravity separators have been developed to increase separation efficiency. Interaction between particle size, speed of rotation, and water pressure of fluidized bed are the most affecting parameters of the separation performance [80].

4.1.2. Centrifugal float–sink separation

Centrifugal sink float technique can separate bituminous coal into clean coal and mineral matter fractions in presence of isopropyl alcohol, carbon tetrachloride, and zinc chloride as a dense medium of specific gravity of 1.4 g/cm³. The separation efficiency depends on medium density, rotor speed, centrifuge time, and particle size distributions [81].

4.1.3. Oil Agglomeration Technique

Vegetable oils, such as soybean or sunflower oils were used oil agglomeration. Lower concentrations cause energy loss. In the case of using 5% refined sunflower oil, a concentrate has 39.5% ash that could be obtained from fine coal has 64.2 % ash. Recovered coal of 29.4% ash is obtained by decreasing oil concentration to less than 5%. These results showed that by using vegetable oils in agglomeration, a good recovery of fine coal can be obtained. Moreover, more than 40% of the waste of fine coal can be saved depending on product quality [82].

4.1.4. Flotation Technique

Fine coal is defined as less than 0.5 mm fraction. Flotation is used to treat the declined fine fraction. High grade and recovery of clean coal were obtained from high ash coal using resinite flotation depending on the frothier type. Wet screening, grinding and pH control can improve the grade [83].

The column flotation showed higher separation efficiency than that of mechanical or conventional flotation. The most effective parameters on the efficiency of column flotation are the flow rate of air and wash water; and the dose of collector and frothier. At optimum conditions values of the process parameters of air and wash water flow rates, feed solids concentration. By using MIBC as a frothier, (DMU-101 as a collector and SMP as a depressant, a coal concentrate of 85% recovery with 81% ash removal was obtained [84].

The floatability of coal is affected by its surface oxidation. Both physical and chemical properties are affected. The zeta potential of coal particles decreases because of oxidation. Promoter addition during the grinding process reduces the surface attrition. Fresh surfaces adsorb promoters easily and thus increase hydrophobicity. At neutral pH, the charge on the coal surface is negative. The adsorption of collector molecules on its surface is hindered. Thus, neutral pH makes the flotation more effective [84].

Coal cleaning using mechanical flotation showed that the concentrate needs more cleaning. So, the rougher concentrate must be refloating to reduce ash content. Clean coal produced by single-stage column flotation is better than mechanical flotation especially with low air velocity [85].

4.1.5. Effect of Ultrasonic Energy

Washing coal using low-energy ultrasonic is a good technique for the removal of sulfur. It could be reduced to less than 1%. The maximum removal was achieved with minimum concentration, conditioning time, and the dose of used alkali with ultra-sonication. A replacement of other conventional coal cleaning methods is carried out for the reduction of energy, treatment time, and reagent volume and concentration. It may be used on a large-scale for high sulfur and ash coals around the world [86]. Low-grade coal cleaning using low energy ultrasonic energy is effective. It was found that the low-energy ultrasonic could remove all impurities such as sulfur, phosphorus, and ash in hydrogen peroxide solution in a short treatment time. It is considered a green process [87].

4.1.6. Effect of Microorganisms

Bacteria were used in bio-flotation and bio-flocculation processes for cleaning coal. Bacteria can be adsorbed onto mineral surfaces. The adsorption is based on electrostatic charges. Bacteria followed coal surface charge after their adsorption. The adsorption process depends on pH-dependent. The maximum adsorption for all bacteria was showing at pH 3. It noted that Bacillus subtilis is the best type for ash and sulfur removal. The removal order of impurities follows the sequence of bacteria adsorption. The cleanest coal is achieved with bacteria of higher adsorption, [88].

4.1.7. Post Treatment of exhaust coal burn

The SO_2 emissions are no longer accepted according to the environmental regulations. Thus, SO_2 gas must be removed from flue gases. There are different techniques for emission reduction:

1. Scrubbing solution:
   It is carried out in alkaline sorbent, usually limestone or lime, or seawater.
2. Scrubbing with a spray:
   It is a different technique using similar sorbent solutions.
3. Wet sulfuric acid process:
   It produces commercial sulfur which is used for sulfuric acid production.
4. SNOX flue gas system:
   It removes sulfur dioxide, nitrogen oxides, and particulates from flue gases.
5. Dry sorbent injection systems.

Flue-gas desulfurization (Fig.4) can remove more than 95% of the SO_2 from the flue gases [89]. SO_2 can be oxidized in the presence of an extra amount of oxygen gas into sulfur trioxide (SO_3). Temperature enhances the oxidation process.
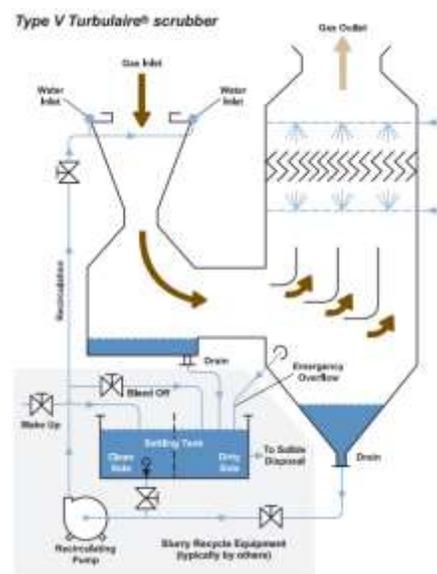

Figure 4: Schematic design of the absorber of an FGD

The SO_3 gas can be formed using catalytic reactions depending on the metals in the fuel. The catalytic reaction is true for heavy fuel oil, due to the presence of vanadium with a significant

amount. SO_3 gas forms a liquid aerosol known as sulfuric acid (H_2SO_4) mist that is very difficult to remove. Generally, about 1% of sulfur dioxide will be converted to SO_3. Sulfuric acid mist causes a series of hazardous. Wet electrostatic precipitators can treat this issue [90].

FGD (flue-gas desulfurization chemistry) systems are carried out in two stages:

1- Fly ash and other SO_2 gas are removed. The removal is carried out for both fly ash and SO_2 gas in one scrubbing vessel. The flue gas passes through an electrostatic precipitator or wet scrubber to remove the fly ash removal device. Then passing in the SO_2-absorber. However, as a dry injection or spray dryer operations, SO_2 is first reacted with the sorbent, and then the flue gas passes through a particulate control device [91].

2- Wet FGD systems in which the flue gas exiting the absorber is saturated with water and still contains some SO_2. These gases are highly corrosive to any stream equipment. To minimize corrosion, the gases were reheated to a temperature above their dew point or using materials of construction and designs that allow equipment to withstand the corrosive conditions [92].

Scrubbing in calcium hydroxide (lime) solution, calcium sulfate is formed according to the following reaction:

$$Ca\,(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$$
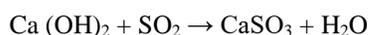
Scrubbing in magnesium hydroxide solution, magnesium sulfite is formed according to the following reaction:

$$Mg\,(OH)_2 + SO_2 \rightarrow MgSO_3 + H_2O$$
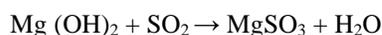
Forced oxidation is another technique in which further oxidation of the $CaSO_3$ (calcium sulfite) to produce $CaSO_4 \cdot 2H_2O$ (gypsum):

$$CaSO_3 + \tfrac{1}{2}O_2 \rightarrow CaSO_4$$

Another technique in which the SO_2 is absorbed in the seawater and then oxygen is added to form sulfate ions SO_4^{2-} and free H^+. The carbonates in seawater shift the carbonate equilibrium to release CO_2 gas:

$$SO_2 + H_2O + \tfrac{1}{2}O_2 \rightarrow SO_4^{2-} + 2H^+$$

$$HCO^{3-} + H^+ \rightarrow H_2O + CO_2$$
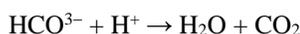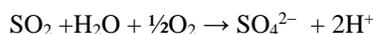
Although there are no technical problems for sulfur dioxide removal by available flue gas cleaning technologies, NO_x removal needs to be further developed. The mitigation of non-condensable gases is an important operation issue for large-scale oxy-fuel combustion plants, [93].

4.2. Oil Shale

Although oil shale can be used as a fuel for thermal power-plants, the oil shale may be used in the production of different products. Fibers, carbon adsorber, carbon black, resins, glues, tanning agents, mastic, bitumen of road, cement, bricks, glass, rock-wool, construction and decorative blocks, soil-additives,

and pharmaceutical products were produced from oil shale[94]. But, these products remain in their experimental stages [95].

In 1946 a marine type of Dictyonema shale served for uranium production in Sillamae, Estonia. Sweden used alum shale for the same purposes [95].

Although oil shale gas has served as a substitute for natural gas [96, 97], in 1972, coal liquefaction was less expensive, generating more oil, and creating fewer environmental impacts than extraction from oil shale. It noted that conversion of 650 liters of oil per one ton of coal, as against 150 liters of shale oil per one ton of oil shale [98].

The viability of oil shale as a source of energy lies in the ratio of the energy produced by shale to the energy used in its mining and processing. It is estimated that the various known oil-shale deposits are varying between 0.7–13.3 [99].

According to IEA most of the produced oil shale is used in energy production. It can be provided by burning the spent shale or oil-shale gas [100]. The water needed in the oil shale retorting process make additional economic consideration and also, it may be a problem in areas with water scarcity.

The kerogen in oil shale formations differs widely, and the economic feasibility of its extraction is highly dependent on international and local costs of oil [30].

$$\text{Kerogen} \rightarrow \text{Oil} + \text{Gas}$$
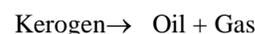
Usually, oil shale exploitation includes mining followed by shipping elsewhere. After which it may be burned directly to generate electricity. Sometimes, it undertakes further processing [101].

The pyrolysis process is a process of kerogen conversion into shale oil (synthetic oil) or shale gas. The process involves heating oil shale in the absence of air to the temperature of kerogen decomposition. It is converted to gas, condensable oil, and solid residue. It usually takes place at 450 - 500°C[102]. There are four known technologies in use. They are Kiviter, Galoter, Fushun, and Petrosix Processes, Figure 5, [103, 104].
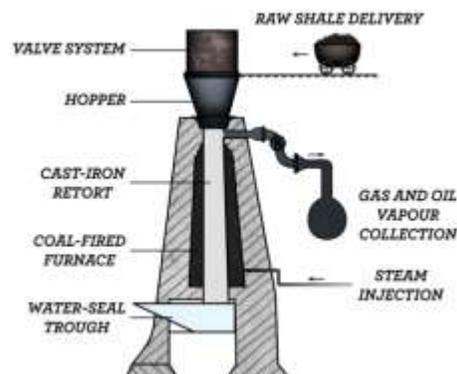

Figure 5: Kiviter, Galster and Petrosix Processes

The Kiviter process is an internal combustion technology. The Kiviter retorter is a vertical cylindrical vessel. The coarse oil shale is heated with recycled gases, steam, or air [104]. The vapors and evolving gases condensed. The non-condensable

gases are fed back to the retort. Recycled gas cools the spent shale, and then leaves the retort through a water-sealed discharge system [101]. The Kiviter process causes water pollution. It uses large amounts of water which is polluted with solid waste residues. It contains soluble toxic substances causing environmental problems, [105].

Galster process is aboveground oil shale retorting technology. It is a type of hot recycled solids technology [106]. A horizontal cylindrical rotating kiln retorter is used [107]. The retorting is carried out crushed oil shale into fine particles to less than 25 mm. The crushed oil shale is dried in a fluidized bed drier with hot gases. The dry product is preheated to 135°C. The particles are separated from gases using an air classifier. The ratio of oil shale ash to raw oil shale is 3:1. The oil vapors and gases are cleaned from solids by cycling and condensed. The condensed oil is separated from gases[108]. Galster process has higher thermal and technological efficiency. It obtains a high oil recovery ratio. The oil yield is reached up to 90%. The retort gas is 48 m^3/ton. Although the oil quality is good, the equipment and capacity are relatively low. The main advantage is that this process causes minimum pollution than internal combustion technologies. It uses less water. But it still generates carbon dioxide as also carbon disulfide and calcium sulfide, [107-109].

The Fushun process is an internal combustion technology. It includes external gas heating [110]. It uses a vertical cylindrical retorter. The oil shale is crushed to particle size range 10 to 75 mm. it fed on the top of the retorter. In the upper section of the retorter, the oil shale is dried and heated. The hot gases cause the decomposition of rock. The produced oil vapor and gases move from the bottom[111]. The Fushun process has small investments and a stable operation. It is characterized by high thermal efficiency, but it consumes high water. It is not suitable for fine ores or of oil content lower than 5% [112].

Petrosix is the largest world surface oil shale pyrolysis retort with 11 meters diameter vertical shaft kiln, operational since 1992. It is located in Brazil, and it is owned and operated by the Brazil energy company Petrobras, [113].

The beneficiation of oil shale is based on the difference in both the physical and chemical properties of organic and inorganic constituents. By controlling particle dispersion in aqueous slurry, the kerogen particles are hydrophobic. Thus, the hydrophilic mineral matter can be separated by using oil agglomeration [114]. There are many techniques for mineral separations. The sink-float technique is based on density differences. Froth flotation is based on hydro-phobicity or wet-ability. Kerogen can be extracted with organic liquids. Also, the mineral particles can be wetted, and thus it is extractable with water [115].

In South African, oil shale is ground with water in a porcelain ball mill. The grinding is continued after the addition of oil to form a paste of the organic fraction. The mineral matter became suspended in the aqueous phase. It was discarded. The oily paste was solvent washed, dried, and analyzed. The results show that the ash content was reduced from 40% to about 10% [116].

Brunswick oil shale contains 58% mineral matter. It was pre-ground in a heavy gasoil before the introduction of water. After sixteen hours of grinding, the mineral content is reduced to 34% [117].

Green River oil shale is treated with a 5 percent acetic acid solution. Thus, the carbonate minerals are removed before grinding. Water and normal octane were used as grinding mediums. The aqueous suspension is removed. It is replaced with fresh water. The results showed that the mineral content is reduced from 75% to 16% [118].

Bitumen impacts the surface chemistry of oil shale particles. Releasing of bitumen because of the particle size reduction or grinding to a particle size less than 100 μm. The release of bitumen coats the organic-rich surface. Decreasing of selectivity during flotation with decreasing particle size fineness is known as the "smearing effect". Bitumen affects organic-rich oil shale particles as well as inorganic entities. It means that the difference between hydrophilicity and hydrophobicity was lost with bitumen releasing. It harms separation efficiency between organic and inorganic portions. So, it is important to preserve the native surface properties of oil shale particles during grinding. Also, the fineness degree to which the oil shale particles lose their surface characteristics must be determined. It means the critical size for oil shale beneficiation to avoid over-grinding that would allow the release of bitumen, [119].

Flotation of El-Nakhil Oil shale, Qussier, Eastern Desert, Egypt, using drops of Procol (F890) as a frothier with or without collectors such as Kerosene, sodium oleate or dodecyl amine acetate shows similar floatability trends. A higher reduction of ash content with low recovery was achieved by decreasing the pH values. With increasing the pH, a higher flotation yield is obtained due to increasing froth stability. The selectivity is decreased at higher pH. For particle size less than 90μm and more than 63 μma better response to the flotation process than that for size fraction (–250+90 μm). Higher selectivity at acidic medium requires large amounts of acid. The acid leaching may release some kerogen. Thus, a decrease in the ash content of the float is expected, [120].

Froth flotation technique can upgrade oil shale. As mentioned before, the particle size affected both the yield and grade and thus the separation efficiency. The grinding to ultra-fine particle sizes must be avoided, it is economic consideration. The particle size lower than 75 μm, need lower frothier and collector doses. On the other hand, flotation of particles more than 150 μm showed higher selectivity than that for less than 75 μm particles. It is noted that the higher separation efficiency was achieved with a particle size of 500 - 150 μm. By increasing frothier and collector dosages, both yield and organic recovery were increased. The yield is strongly affected by the types of frothier [121].

Acid leaching of Egyptian weathered oil shale showed that the acid-soluble fraction increases with decreasing the ash content as acetic acid concentration increases. Calcite and fluorapatite disappeared from the residue after treatment with a 5% HCl solution. The acid-soluble fraction was 37 and 42 wt% by using 5 and 10% HCl, respectively. 10% HNO$_3$ solution could dissolve all fluorapatite present in the sample whereas 20% HNO$_3$

solution could dissolve almost all carbonates. 20% CH_3COOH solution could dissolve almost all carbonates. Acetic acid produces minimum TOC value and oil yield comparing to HCl and HNO_3 leaching [122].

In 2016, the world resources of oil shale are equivalent to 6.05 trillion barrels (962 billion cubic meters) of oil. In 2018, the U.S. Energy Information Administration (EIA) estimated that about 6.5 million barrels of oil per day were produced from tight oil resources in the United States. This is equivalent to about 59% of total U.S. crude oil production. Tight oil is the oil embedded in low-permeable shale, sandstone, and carbonate rock formations [123].

Beneficiation and upgrading of Egyptian energy source mineral ores, such as coal and oil shale presented many studies for upgrading them were done[88, 124-132], including selective oil agglomeration, reverse flotation, enhanced gravity separation (Falcon Concentrator), column flotation, flocculation using acrylamide-acrylic copolymer, application of microorganisms such as Bacillus subtilis, Mycobacterium Pheli, Paeni Bacillus Polymyxa.

The results showed that gravity separation techniques are more economical than other techniques due to their low operation and capital costs. Moreover, gravity separation techniques have the advantage to be environmentally friendly as they are chemically free. Finally, on the technical level, the concentrates of Egyptian Coal by the latter technique meet the standard coal specifications. Also, gypsum and pyrite as wastes of burning coal were converted into useful products such as iron and sulfur elements through the thermo-chemical process [133-135].

Egyptian oil shale from the Safaga area (Red Sea Coast) and carbonaceous shale from the Abu-Zenima area (West Central Sinai)were discovered and studied [136-139]. The obtaining concentrates showed that they have high organic matter suitable for the retorting process. Attrition scrubbing, hydro-cyclone separation, jigging, enhanced gravity separation, and froth flotation were used for increasing the organic matter content.

Mineralogical studies of Egyptian oil shale showed that it contains a bituminous calcareous claystone. The main impurities are quartz, apatite, and pyrite minerals. The carbonaceous shale type contains carbonaceous matter with quartz and clay minerals. The oil shale of the Rabah mine is richer in carbonates as calcite and phosphorous as apatite. On the other hand, Abu-Zenima carbonaceous shaleis enriched in quartz, clay, and gypsum minerals. Its silica, alumina, and organic matter contents are much higher than that of Rabah oil shale. The former contains 35.2% organic matter as compared with 30.6% in the latter. Also, there are considerable amounts of calcium oxide and iron oxides. By jigging technique, a concentrate of 70.26% organic matter with 54.06% recovery is obtained. A flotation concentrate has an organic matter of 54% with 65% recovery. Flotation of overflow fraction with kerosene as a collector obtained float containing 67% organic matter with 85% recovery [136].

Mineralogical analysis of Egyptian oil shale (Wadi El-Nakhil) showed that the shale matrix is composed of the lamina which is consisted of carbonate and argillaceous material (rich inorganic matter). Quartz and pyrite were dispersed in the matrix. Phosphate is found because of the remnants of marine animals. It is rich in the aliphatic and aromatic matrix. It is characteristic of a higher content of calcium oxide, sulfur, silica, alumina, and iron oxide.

An Enhanced gravity separator (Falcon concentrator) could produce a concentrate of 40% kerogen with 88% recovery [137-138]. Column flotation showed that there are significant interactions of airflow rate with frothier concentration, kerosene collector dosage, and froth depth. In contrast, the solids concentration, feed flow rate and wash water flow rate have fewer effects on both grade and recovery. At 15% solid content, 0.49 cm/s feed flow rate, 40 cm froth highest, and in presence of 0.5 kg/ton kerosene collector dosage, the grade and recovery were 54% and 80%, respectively, [139].

4.3. Nuclear Energy Fuels

Uranium 235 is the most common nuclear fuels used. Ores are chemically processed using leaching and solvent extraction. Leaching produces yellowcake, which is tri-uranium octa-oxide. Uranium is obtained as pure uranyl nitrate. It is decomposed to uranium trioxide (UO_3), by heating. Then it is reduced to the dioxide form, UO_2, by hydrogen. The dioxide is converted to tetrafluoride, UF_4, by hydrogen fluoride gas. Pure metal is produced by electrolysis or chemical reduction [42].

Naturally, uranium metal is composed of 0.7205% U-235, which is the fissile isotope of uranium. U-238 isotope is the remaining mass (99.274%). It contains a small amount of U-234 isotope (0.0055%). Uranium-238 does not react with slow neutron fission; however, it can react with neutrons to form a fissile isotope of plutonium, Pu-239. Thus U-238 is known as the fertile material. Both uranium isotopes have the same chemical behavior. They differ slightly in their mass. The small mass difference allows the isotopes to be separated. The uranium fuel for power reactors must be containing 0.8 to 8.0% U-235. It is known as low enriched uranium. Weapons-grade must have a higher content of Uranium 235. Its concentration is greater than 90% U-235 [140].

- *Gaseous Diffusion*

It is based on the effusion difference of molecules. If gas is passed from a vacuum through a porous barrier, the gas effusion rate is inversely proportional to the square root of its mass. Thus, the heavier gas molecules will pass slower than that of the lighter ones. Because Uranium hexafluoride (UF_6) is volatile; it is used in this process, Figure 6, [141].

- *Electromagnetic Separation*

It is based on the circular path of a charged particle in a magnetic field depends on its mass. Thus, uranium tetrachloride chloride ions of both U-235 and U-238 are expected to have slightly different paths by moving in a magnetic field. The expected path radius for U-238 ions is larger than that of U-235 ions, Figure 7.
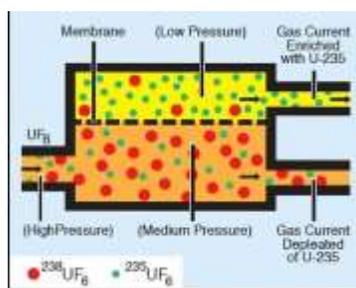
**Figure 6: Separation by Gaseous Diffusion.**
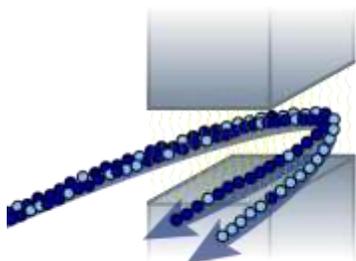
Figure 7: **Electromagnetic Separation**

- *Thermal Diffusion*

It is based on, the behavior of heat transfers across a thin layer of liquid or gas. By cooling a film on one side and heating the other side produces convection currents. Thus, an upward flow on the hot surface and a downward flow along the cooler side occur. Thus, the $235UF_6$ molecules are diffused toward the warmer surface. The $238UF_6$ goes toward the cooler side.

- *Centrifuge Enrichment*

Even though centrifugation has lower energy consumption (5% of that required for gaseous diffusion). It needs shorter separation times, and a modular design. Thus, it is the preferred method for enriching uranium. It can produce higher enrichment uranium from a single centrifuge than from a single gaseous diffusion stage. The process must be repeated in a series of connected centrifuges known as a cascade to obtain the desired concentration of enriched uranium, Figure 8 [142].
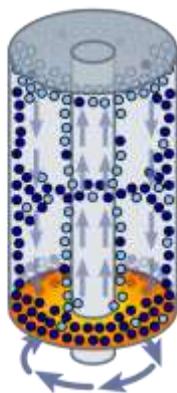
Figure 8: Centrifuge Separation

- *Fuel fabrication*

Annually; 27 tons of fresh fuel is required for 1000 MWe nuclear reactors. A coal power station requires more than two and a half million tons of coal to produce the equivalent energy as electricity. Enriched UF_6 is converted to uranium dioxide (UO_2) powder. The powder is pressed to form small fuel pellets, which are then heated to make a hard-ceramic material. The pellets are inserted into thin tubes to form fuel rods, [143].

The down blending process is a process for converting highly enriched uranium into low enriched, reactor-grade uranium. It is used to convert the vast nuclear weapons stockpile of the former Soviet Union, [144].

Liquid fuels are the solution of nuclear fuel which has numerous operational advantages. Liquid-fuel reactors have significant safety advantages. This is because their inherently stable, their ability to be drained rapidly, and xenon gas releasing which acts as a neutron absorber. Molten salt fuels can be dissolved directly in the molten salt coolant such as liquid fluoride thorium reactor (LFTR). Uranyl salt solutions were used in aqueous homogeneous reactors (AHRs), [145].

Thorium element has been extracted from monazite ore through a complex multi-stage process. The monazite sand ore is dissolved in hot concentrated sulfuric acid (H_2SO_4). Thorium is extracted as an insoluble residue. It is concentrated in the organic phase of the amine solvent. Then it is separated by using an electrolyte solution such as nitrate, chloride, hydroxide, or carbonate. Thus, thorium is returned to an aqueous phase. Finally, thorium is precipitated and purified, [146].

There are many techniques to produce thorium metal:

- Through electrolysis of anhydrous thorium chloride in a fused mixture of sodium and potassium chlorides.
- By reduction of thorium oxide using calcium.
- By reduction of thorium tetrachloride mixed with anhydrous zinc chloride.
- By reduction of thorium tetrachloride with an alkali metal [147].

5. SUMMARY & CONCLUSIONS

Energy Source Mineral is any substance that comes from the Earth which can produce energy. Generally, energy resources are conventional: such as wood, coal, oil, natural gas, and electricity; and non-conventional such as Solar, wind, biogas, and atomic energy. Energy derived from Sun is biomass energy because of photosynthesis of organic byproducts. Biomass energy is stored as fossil fuels (oil, natural gas, oil shale, tar sands, and Coal) through a series of chemical reactions.

Oil shale is a shame that contains organic matter. This organic content has not decomposed completely to produce oil. Coal is a sedimentary rock produced as a result of a large accumulation of dead plants.

Nuclear fuel must include heavy fissionable metals. Nuclear fuel is shaping as rods of fuel material, mixed with neutron reflecting materials. Uranium-235 (^{235}U), Plutonium-239 (^{239}Pu) and Thorium-232 (^{232}Th) are the most common fuels.

The global coal production is about 7 billion tons while there is a small underground coal mine in the Sinai Peninsula, Egypt. Although its production is 0.36 Mt/y, the national demand is 1.2 Mt/y. It is non-coking which must be blend with imported metallurgical coal. The recoverable amount is 17.637 million Tons.

Gravity concentration, when feasible, is preferred over flotation. For environmental regulations, SO_2 gas emissions have been enacted. In many countries, SO_2 is reduced from flue gases by different techniques and methods.

Total oil shale resources are about 689 gigatons. It is equivalent to 4.8 trillion barrels. Egyptian Oil Shale in Safaga-Quseir estimated reserves in the Eastern Desert of Egypt is equivalent to about 4.5 million barrels. Another reserve in the Abu-tartur area of the Western Desert is estimated to be about 1.2 million barrels. Oil shale can be burned directly to generate electricity. It may be used after further cleaning processes. Pyrolysis is the most operation used for oil shale. Though its conversion of the kerogen into shale oil and shale gas. It is based on heating the shale in the absence of oxygen at $450 - 500°C$ to decompose (pyrolysis) kerogen. Thus, gas, condensable oil, and solid residue were obtained.

Egyptian Maghara Coal could meet the standard coal specifications through enhanced gravity separation. Conversion of Coal cleaning By-product to valuable products was carried out at CAER, University of Kentucky, USA. Metallic iron and elemental sulfur were produced from the thermo-chemical processing of gypsum & pyrite as wastes of coal cleaning.

Organic matter could be increased in oil shale from Safaga and Abu-Zenima, west Central Sinai, Egypt. Different techniques were used such as attrition scrubbing; hydro-cyclone, jig, and froth flotation. A product of column flotation contains 67% organic matter and 85% recovery. The flotation is carried out for overflow fraction by using kerosene. A concentrate of 40% kerogen with 88% recovery was obtained by enhanced gravity separation of Egyptian Wadi El-Nakhil oil shale. A maximum grade and recovery of 54% and 80% were achieved by using column flotation.

Uranium is occurring in Earth's crust with abundant, but it is 40 times as silver. Nuclear fuel is making from the uranium ore by extracting uranium firstly then concentrated in uranium-235 isotope. Although there are hundreds of uranium-containing minerals only a few of them are commercially feasible. Uraninite (uranium dioxide) and pitchblende are the common ores.

Uranium was found in many areas, in Egypt. It is found in Sinai, Red Sea, Upper Egypt, and the Gtar area, near Hurghada.

Uranium element contains 0.72% U-235 (fissile isotope). The remaining includes 99.27% U-238 and a small amount of U-234 (0.0055%). Uranium fuel for power reactor must beeps to 8.0% U-235. Weapons-grade uranium must contain highly enriched uranium greater than 90% U-235. There are different enrichment techniques such as electromagnetic separation, gaseous and thermal diffusion, and centrifuge.

References

1- https://www.tulane.edu/~sanelson/eens1110/energy.htm (accessed in October 2019).
2- B.C. McLellan, G.D. Corder, D.P., K.N. Ishihara, Renewable energy in the minerals industry: a review of global potential, Journal of Cleaner Production 32, 32-44, (2012).
3- http://earthsci.org/education/teacher/basicgeol/resource/resource.html, (accessed in October 2019).
4- http://en.wikipedia.org/wiki/Nuclear_fuel,(accessed in Oct. 2019).
5- https://commons.wikimedia.org/w/index.php?curid=1327479, by Nicolas Lardot, (accessed in October 2019).
6- G. Audi, O. Bersillon, J. Blachot, A.H. Wapstra, The NUBASE evaluation of nuclear and decay properties (PDF). Nuclear Physics A. 729 (1): 3-128. Bibcode: 2003 NuPhA.729, 3A. CiteSeer X10.1.1.692.8504doi:10.1016/j.nuclphysa.2003.11.001, (2013).
7- M. Blander, Calculations of the Influence of Additives on Coal Combustion Deposits, Argonne National Laboratory. p. 315. Retrieved 17 December, (2011).
8- "EIA, International Energy Statistics, Coal, Recoverable Reserves, Retrieved 31 May, (2012).
9- http://www.eia.gov/coal/reserves/, (accessed in October 2019).
10- Coal: Resources and Future Production, Energy Watch group, 28 March 2007 (2007).
11- BP Statistical review of world energy 2012, British Petroleum. Retrieved 18 August, (2011).
12- EIA International Energy Annual – Total Coal Consumption (TST).Eia.gov. (2013).
13- EIA International Energy Annual: Coal Overview 2010. Eia.gov. Retrieved on 24 August (2012).
14- EIA International Energy Annual – Total Coal Exports (TST). Tonto.eia.doe.gov., (2012).
15- World Metallurgical Coal Flows By Importing Regions and Exporting Countries, eia.doe.gov, (2012)
16- World Coal Flows by Importing and Exporting Regions. Eia.doe.gov., Retrieved August (2012).
17- International Energy Annual-Total Coal Imports (Thousand Short Tons). Tonto.eia.doe.gov., Retrieved on 24 August, (2012).
18- http://www.merriam-webster.com/dictionary/steam%20coal, (accessed in October 2019).
19- http://www.britannica.com/EBchecked/topic/564463/steam-coal, (accessed in October 2019).
20- https://en.wikipedia.org/wiki/ New_World_Resources, (accessed in October 2019).
21- EIA International Energy Statistics: Coal: Consumption, Retrieved 10 June, (2009).
22- https://en.wikipedia.org/wiki/Coal, (accessed in October 2019).
23- http://egypt.opendataforafrica.org/mibvsrd/egypt-coal-reserves, (accessed in October 2019).
24- R.V. Tyson, Sedimentary Organic Matter. Organic faces and polynofaces. Chap.and Hall, Londons, 615 (1995).
25- Geochemistry-Earth's System Processes Edited by Dr. Dionisios Panagiotaras, ISBN 978-953-51-0586-2, (2012).

26- U. Lille, I. Heinmaa, T. Pehk, Molecular model of Estonian kukersitekerogen as evaluated by 13C MAS NMR spectroscopy // Fuel., 82, 7, 799-804, (2002).

27- J. Francu, H. Barbra; L. Ben; S. Andres, V. Mihkel, A study on the EU oil shale industry viewed in the light of the Estonian experience, A report by EASAC to the Committee on Industry, Research and Energy of the European Parliament. European Academies Science Advisory Council.1-2, (2011).

28- N.E. Altun, C. Hiçyilmaz, J.Y. Hwang, A. SuatBağci, M.V. Kök, Oil Shales in the world and Turkey; reserves, current situation, and future prospects: a review, Oil Shale. A Scientific-Technical Journal, Estonian Academy Publishers23 (3): 211-227. ISSN 0208-189X, (2007).

29- J.R. Dyni, Geology and resources of some world oil-shale deposits. Scientific Investigations Report 2005–5294, U.S. Department of the Interior. U.S. Geological Survey, (2007).

30- Chapter 3, Petroleum and Other Liquids Fuels, International Energy Outlook 2007, Energy Information Administration. May 2007. DOE/EIA-0484, (2008).

31- Youngquist, Walter, Shale Oil -Elusive Energy, Hubbert Center Newsletter (Colorado School of Mines) (4), (2007).

32- O. Bekri, Possibilities for Oil Shale Development in Morocco, Energeia (University of Kentucky, Center for Applied Energy Research) 3 (5): 1–2, (2008).

33- J. Qian, J. Wang, S. Li, Oil Shale Development in China (PDF), Oil Shale. A Scientific-Technical Journal(Estonian Academy Publishers) 20 (3): 356-359, ISSN0208-189X, (2007).

34- H. Yousef; J. Alali; S. Sawaged, Oil Shale Resources Development In Jordan, Amman: Natural Resources Authority of Jordan, (2008).

35- L. Jean, Review on oil shale data, Oil Shale. A Scientific-Technical Journal (Hubbert Peak), (2007).

36- Russell, Paul L., Oil shales of the world, their origin, occurrence and exploitation, 1st ed., Pergamon Press.162–224. ISBN 0-08-037240-6, (1996).

37- Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries outside the United States, U.S. Energy Information Administration (EIA), (2013).

37- Our Egyptian Region, Apache Corporation, New York Times, Retrieved June 14, (2013).

39- Egypt Region Overview, Apache Corporation, New York Times, Retrieved June 14, (2013).

40- Micheal J., Apache to Sell Stake in Egyptian Holdings to Sinopec for $3.1 Billion, New York Times, Retrieved August 30, (2013).

41-http://www.world-nuclear.org/nuclear-basics/how-is-uranium-ore-made-into-nuclear-fuel-/, (accessed in Oct. 2019)

42-http://www.infoplease.com/encyclopedia/science/uranium-natural-occurrence-processing.html, (acc. in Oct. 2019).

43- Exploration drives uranium resources up 17%, World-nuclear-news.org., Retrieved 12 September (2008).

44- Global Uranium Resources to Meet Projected Demand, International Atomic Energy Agency, Retrieved (2007).

45-http://en.wikipedia.org/wiki/Uranium, (accessed in October 2019).

46- Uranium Mining and Processing in South Australia. South Australian Chamber of Mines and Energy, (2007).

47- Uranium recovery from Seawater, Japan Atomic Energy Research Institute, Retrieved 3 September (2008).

48- How long will nuclear energy last?World-nuclear-news.org., Retrieved 29 March (2007).

49- World Uranium Production, UxC Consulting Company, LLC, Retrieved 11 February (2007).

50- http://www.egyptindependent.com//news/egypt-discovers-large-amounts-uranium, (accessed in October 2019).

51- NNDC contributors; Alejandro A. Sonzogni (Database Manager), Chart of Nuclides, Upton (NY): National Nuclear Data Center, Brookhaven National Laboratory, (2008).

52- DOE contributors, Oklo: Natural Nuclear Reactors, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, (2008).

53- D.C. Hoffman, F.O. Lawrence, J.L. Mewherter, F.M. Rourke, Detection of Plutonium-244 in Nature, Nature 234 (5325): 132–134.Bibcode: 1971 Natur. 234. 132H, (1985).

54- IAEA-TECDOC-1450 Thorium Fuel Cycle-Potential Benefits and Challenges (PDF). International Atomic Energy Agency. May 2005. Retrieved 15 March (2012).

55- THORIUM Agency for Toxic Substances and Disease Registry, July (1999).

56- Press Trust of India, Over 1.25 MT thorium reserve found in 3 years, Business Standard. Retrieved 22 August (2013).

57- C.R. Hammond, The Elements, in Handbook of Chemistry and Physics 81st edition, CRC press.ISBN 0-8493-0485-7, (2004).

58- Monazite-(Ce) mineral information and data, Retrieved 18 May (2009).

59-U.S. Geological Survey, Mineral Commodity Summaries – Thorium, January (2008).

60-Thorium: Is It the Better Nuclear Fuel? Cavendish Press, Dec (2008).

61- Jayaram, K.M.V., An Overview of World Thorium Resources, Incentives for Further Exploration and Forecast for Thorium Requirements in the Near Future, Department of Atomic Energy, PDF Report, (2011).

62- Total World Electricity Generation by Fuel (2006). Source: IEA (2008).

63- Coal reserves, coal exploration, World Coal Association, Worldcoal.org. (2012).

64- Figure ES 1. U.S. Electric Power Industry Net Generation, Electric Power Annual with data for, U.S. Energy Information Administration, (2010).

65- Blast furnace steelmaking cost model. Steelonthenet.com. Retrieved on 24 August (2012).

66- Höök M., Aleklett K., A review on coal-to-liquid fuels and its coal consumption, International Journal of Energy Research 34 (10): 848.doi:10.1002/er.1596, (2010).

67-Mahony B., Moulston I., Wilkinson H.C., Study of the relationship between the phosphorus content of coal and coke. Fuel, 60: 355-358 (1981).

68- P. Burchill, R.W. Howarth, D.G. Richards, B.J. Sword, Solid-state nuclear magnetic resonance studies of phosphorus and boron in coals and combustion residues. Fuel, 69:421-428 (1990).

69- S.M. Kovach, J. Bennett, Coal liquefaction, 1: catalysts present in coal. Am. Chem. Soc. Div. Fuel Chem. Preprints, 20(1): 143-160 (1975).

70- J.L. Howard, D.F. Amos, W.L. Daniels, Phosphorus, and potassium relationships in southwestern Virginia coal mine spoils. J. Environ. Qual., 17(4): 695-700 (1988).

71- K.K. Bertine, E.D. Goldberg, Fossil fuel combustion and the major sedimentary cycle. Science, 173: 233-235 (1971).

72- A.B. Ronov, G.A Korzina, Phosphorus in sedimentary rocks. Geochemistry, 8: 805-829 (1960).

73- R.R. Ruth, H.J. Gluskoter, N.F.Shimp, Occurrence and distribution of potentially volatile trace elements in coal: a final report. Illinois State Geological Survey Environmental Geology Notes, 72, 96, (1974).

74- R.A. Durie, H.N.S. Schafer, Inorganic constituents in Australian coals: IV-phosphorus and fluorine their probable mode of occurrence. Fuel, 43:31 41 (1964).

75-http://www.intinno.com/files/iitkgp-intinno-usage-case-study .pdf, (accessed in October 2019).

76- Y. Xuliang, Z. Yuemin, L. Zhenfu, S. Shulei, D. Chenlong, D. Liang, Fine coal dry cleaning using a vibrated gas-fluidized bed, Fuel Processing Technology 106, 338–343, (2013).

77- K.S. Ranjeet, D. Avimanyu, Analysis of separation response of Kelsey centrifugal jig in processing fine coal, Fuel Processing Technology 115, 71-78, (2013).

78- R.Q. Honaker, N. Singh, B. Govindarajan, Application of Dense-Medium in an Enhanced Gravity Separator for Fine Coal Cleaning Minerals Engineering, 13, 4, 415-427, (2000).

79- J.S. Kroll, E. Climent, F. Bourgeois, Physical analysis, and modeling of the Falcon concentrator for beneficiation of ultrafine particles, Inter. J. Mineral Proc. 121, 39–50, (2013).

80- T. Uslu, E. Sahinoglu, M. Yavuz, Desulfurization and deashing of oxidized fine coal by Knelson concentrator, Fuel Processing Technology 101, 94–100, (2012).

81- Z. Aktas, F. Karacan, A. Olcay, Centrifugal float–sink separation of fine Turkish coals in dense media, Fuel Processing Technology 55, 235–250, (1998).

82- M.I. Alonso, A.F. Valde, R.M. Marti, A.B. Garcia, Coal recovery from coal fines cleaning wastes by agglomeration with vegetable oils: effects of oil type and concentration, Fuel 78, 753–759, (1999).

83- A.A. Atia, Flotation of Resinite from High Ash Coal, Minerals Engineering, 12, 2, 229-234, 1999

84- Han O.H., Kim M.K., Kim B.G., Subasinghe N., and Park C.H., " Fine coal beneficiation by column flotation" Fuel Processing Technology 126, 49–59, (2014).

85- Dey S., Paul G.M., and Pani S., Flotation behaviour of weathered coal in mechanical and column flotation cell, Powder Technology 246, 689–694, (2013).

86- B.K. Saikia, A.M. Dutta, L. Saikia, B.P. Baruah, Ultrasonic assisted cleaning of high sulfur Indian coals in water and mixed alkali, Fuel Processing Tech., 123, 107–113, (2013).

87- B.K. Saikia, A.M. Dutta, L. Saikia, B.P. Baruah, Feasibility studies of desulfurization and deashing of low-grade medium to high sulfur coals by low energy ultra sonication, Fuel 123, 12–18, (2014).

88- A.A. El-Midany, and M.A. Abdel-Khalek, Influence of bacteria–coal electrostatic interaction on coal cleaning, Inter. J. of Mineral Processing 126, 30–34, (2014).

89- S.J. Biondo, J.C. Marten, A History of Flue Gas Desulfurization Systems Since 1850, Journal of the Air Pollution Control Association, 27, 10, 948–961, (1977).

90- P.S. Nolan, Flue Gas Desulfurization Technologies for Coal-Fired Power Plants, The Babcock & Wilcox Company, U.S., presented by Michael X. Jiang at the Coal-Tech 2000 International Conference, November, Jakarta, Indonesia, (2000).

91- E.S. Rubin, S. Yeh, D.A. Hounsell, M.R. Taylor, Experience curves for power plant emission control technologies, Int. J. Energy Technology and Policy, 2, 1/2, (2004).

92- M.R. Beychok, Comparative economics of advanced regenerable flue gas desulfurization processes, EPRI CS-1381, Electric Power Research Institute, March (1980).

93- J. Yana, M. Anhedena, R. Fabera, F. Starfelta, R. Pruscheb, Flue Gas Cleaning for CO_2 Capture from Coal-fired Oxyfuel Combustion Power Generation, Procedia 4, 900-907, (2011).

94- J. Francu, B. Harvie, B. Laenen, A. Siirde, M. Veiderma, A study on the EU oil shale industry viewed in the light of the Estonian experience. A report by EASAC to the Committee on Industry, Research and Energy of the European Parliament. European Academies Science Advisory Council.12-13; 18-19; 23-24; 28, (2010).

95-R. John, Geology and resources of some world oil shale deposits, Scientific Investigations Report 2005–5294. US Dept. of the Interior, United States Geological Survey, (2007).

96- F.C. Schora, P.B. Tarman, H.L. Feldkirchner, S.A. Weil, Hydro-carbon fuels from oil shale Proceedings (American Institute of Chemical Engineers) 1:325–330, A77-12662 02-44 (1976).

97- I. Valgma, Map of oil shale mining history in Estonia, Mining Institute of Tallinn Technical University, (2007).

98- J. Laherrère, Review on oil shale data, Hubbert Peak. Retrieved 06-17 (2007).

99- C.J. Cleveland, R. Costanza, C.A.S. Hall, R. Kaufmann, Energy and the U.S. Economy: A Biophysical Perspective, Science (American Association for Advancement of Science) 225 (4665): 890–897. Bibcode: 1984Sci 225, 890C. doi: 10. 1126/science. 225.4665. 890. ISSN 0036-8075. PMID 17779848 (1984).

100- A.K. Mittal, Unconventional Oil and Gas Production. Opportunities and Challenges of Oil Shale Development, Government Accountability Office(2012).

101- M. Koel, Estonian oil shale, Oil Shale. A Scientific-Technical Journal (Estonian Academy Publishers) (Extra), ISSN 0208-189X, Retrieved 11-23 (2008).

102- A.K. Burnham, J.R. McConaghy, Comparison of the acceptability of various oil shale processes (PDF). Golden: 26th Oil shale symposium. UCRL-CONF-226717, (2008).

103- J.O. Jaber, T.A. Sladek, S. Mernitz, T.M. Tarawneh, Future Policies and Strategies for Oil Shale Development in Jordan (PDF). Jordan Journal of Mechanical and Industrial Engineering 2 (1): 31–44. ISSN 1995-6665, (2008).

104- L. Mölder, Estonian Oil Shale Retorting Industry at a Crossroads, Oil Shale. A Scientific-Technical Journal, Estonian Academy Publishers, 21 (2): 97-98. ISSN 0208-189X, (2008).

105- J. Soone, H. Riisalu, L. Kekisheva, S. Doilov, Environmentally sustainable use of energy and chemical potential of oil shale, International Oil Shale Conference. Amman, Jordan: Jordanian Natural Resources Authority, 2–3, (2007).

106- A.K. Burnham, J.R. McConaghy, Comparison of the acceptability of various oil shale processes, 26th Oil shale symposium, Golden, Colorado: Lawrence Livermore National Laboratory. p. 17.UCRL-CONF-226717, (2008).

107- J. Qian, J. Wang, World oil shale retorting technologies, Amman ,Jordan: International Oil Shale Conf., (2008).

108- N. Golubev, Solid heat carrier technology for oil shale retorting, Oil Shale, Scientific-Technical Journal, Estonian Academy, 20 (3Sp.) 324-332. ISSN 0208-189X, (2008).

109- L. Mölder, Estonian Oil Shale Retorting Industry at a Crossroads, Oil Shale. A Scientific-Technical J. (Estonian Academy) 21 (2): 97–98. ISSN 0208-189X, (2008).

110- A.K. Burnham, J.R. McConaghy, Comparison of the acceptability of various oil shale processes, Golden: 26th Oil shale symposium. UCRL-CONF-226717, (2009).

111- J. Purga, Today's rainbow ends in Fushun, Oil Shale. A Scientific-Technical Journal (Estonian Academy Publishers) 21 (4): 269–272. ISSN 0208-189X, (2009).

112- Present development status of oil shale, China Chemical Reporter, (2009).

113- The fuel gas or another fuel is used to heat the external furnace. "The Petrosix Process". Petrobras, (2007).

114- Process for beneficiating oil shale using froth flotation and selective flocculation - US patent, 4673133 A, (2012).

115- Puddingt on, I. E. and Farnard, J. R., Oil Phase Separation, U.S. Patent No. 3,999,765, (1968).

116- F.W. Quass, The Analysis of the Kerogen of Oil Shales, Inst. Pet. J., V. 25, 813, (1939).

117- G.W. Himus, G.C. Basak, Analysis of Coals and Carbonaceous Materials Containing High Percentages of Inherent Mineral Matter, Fuel, V. 28, 57, (1949).

118- J.W. Smith, L.W. Higby, Preparation of Organic Concentrate from Green River Oil Shale, Anal. Chem., V. 32, 1718, (1960).

119- N.E. Altun, Incidental Release of Bitumen during Oil Shale Grinding and Impacts on Oil Shale Beneficiation, Oil Shale, Vol. 26, No. 3, pp. 382–398, ISSN 0208-189X, Estonia, (2009).

120- A.F. Muhammad, M.S. El-Salmawy, A.M. Abdelaal, Potential for Upgrading El-Nakhil Oil Shale by Froth Flotation, Oil Shale, Vol. 30, No. 1, pp. 48–59 ISSN 0208-189X, Estonian Academy Publishers, (2013).

121- C. Tsai, R.E. Lumpkin, Oil shale beneficiation by froth flotation Shirley, Fuel, Vol 63, April 435-439, (1984).

122- A.F. Muhamad, M.S. El-Salmawy, A. Abdelaal, S. Sameah, El-Nakhil Oil Shale: Material Characterization and Effect of Acid Leaching, Oil Shale,Vol 28, No. 4, p. 528–547, (2011).

123- https://www.eia.gov/tools/faqs/faq.php?id=847&t=6, last update September 4, 4 2019 (accessed in November 2019).

124- M.A. Abdel Khalek, B.K. Parekh, Selective Oil Agglomeration of El-Maghara Coal, (Sinai - Egypt) - Journal of Ore Dressing, Turkey, 3, 5, ISSN 1302 – 6798, 39-46, (2001).

125- M.A. Abdel Khalek, Decreasing of Sulfur Content of Maghara Coal by Reverse Flotation Process, Trans. of Egyptian Society of Chemical Engineers, TESCE, V27, N2, 80 - 86, (2001).

126- M.A. Abdel Khalek, B.K. Parekh, Using a Falcon Concentrator, as a New Technology, for Removal of Environmental Pollutants of Egyptian Coal, Journal of Ore Dressing, Turkey, 4, 7, ISSN 1302-6798, 20-28, (2002).

127- M.A. Abdel Khalek, Cleaning of Egyptian Coal by Using Column Flotation to Minimize Environmental Pollution. AFINIDAD, LIX, 497, 34-38, (2002).

128- M.A. Abdel Khalek and G.A. Mahmoud, Flocculation Studies of Fine Coal using Acrylamide and Acrylic Acid Graft Copolymer by Gamma Irradiation, Australian Journal of Basic & Applied Sciences, 5(11): 271-278, (2011).

129- M.A. Abdel Khalek and A.A. Elmaidany, Application of Bacillus subtilis for reducing ash and sulfur in coal, Environmental Earth Sciences, ISSN 1866-6280, 12665-012-2163-4, (2013).

130- M.A. Abdel Khalek and A.A. Elmaidany, Coal–Myco-bacterium pheli interaction and its effect on coal cleaning, Tenside Surfactants & Detergents, 6, 414–419, (2013).

131- M.A. Abdel Khalek and A.A. Elmaidany, Adsorption of Paenibacillus polymyxa and its impact on coal cleaning, Fuel Processing Technology, 113, 52–56, (2013).

132- M.A. Abdel Khalek and A.A. Elmaidany, reducing sulfur and ash from coal using Bacillus subtilis and Paenibacillus polymyxa, Fuel Processing Technology, 115, 589-595, (2014).

133- D. Tao, M.A. Abdel Khalek and B.K. Parekh, Magnetic Separation of Iron Metal Produced from Processing of Pyrite Concentrate Waste, AFINIDAD, LVI, (484), 42-47, Dec., (1999).

134- D. Tao, M. Abdel-Khalek, S. Chen, B.K. Parekh, M. Hepworth, A thermochemical process for utilization of gypsum and pyrite. SME Annual Meeting & Exhibit, Feb. 28- Mar. 1, Salt Lake City, UT, (2000).

135- D. Tao, M. Abdel-Khalek, S. Chen, B.K. Parekh, M. Hepworth, An Investigation of Thermochemical Process for Conversion of Gypsum and Pyrite Waste into useful Products, Advancement in Environmental Research, 5, 277-286, (2001).

136- M.K. Abd El-Rahman and M. Al-Wakeel, Enrichment of organic matter of some Egyptian black shales, Mineral Processing and Extractive Metallurgy (Trans. Inst. Min Metall. C) 116, 3, 189-196, (2007).

137- A. Yehia, F.I. El-Hosiny, S.S. Ibrahim, M.A. Abdel Khalek, R.M. Amin, Characteristics and Upgrading of Egyptian Oil Shale, Petroleum Science and Engineering, 2(2): 30-36 (2017).

138- A. Yehia, F.I. El-Hosiny, S.S. Ibrahim, M.A. Abdel Khalek, R.M. Amin, Upgrading of Egyptian Oil Shale Using Enhanced Gravity Separation, Industrial Engineering, 1 (1): 36-42 (2017).

139- A. Sobhy, A. Yehia, A., F.I. El-Hosiny, S.S. Ibrahim, M.A. Abdel Khalek, R. Amin, Statistical analysis of Egyptian oil shale column flotation, International Journal of Coal Preparation and Utilization, in press, (2019).

140- G. Alexander, About the Enrichment Limit for Research Reactor Conversion : Why 20%?. Princeton University. Retrieved 18 April (2014).

141- https://en.wikipedia.org/wiki/Gaseous_diffusion, (accessed in October 2019).

142- http://www.chemcases.com/nuclear/, (accessed in October 2019).

143- http://www.world-nuclear.org/nuclear-basics/how-is-uranium-ore-made-into-nuclear-fuel-/ (access Oct.2019).

144- http://www.ehow.com/about_4571044_what-enriched-uranium.html, (accessed in October 2019).

145- http://www.aps.org/units/fps/newsletters/201101/hargraves.cfm, (accessed in October 2019).

146- D. Crouse, K. Brown, Amex Process for Extracting Thorium Ores with Alkyl Amines, Industrial & Engineering Chemistry 51 (12): 1461.doi:10.1021/ ie50600 a 030, (1959).

147- C.R. Hammond, The Elements, in Handbook of Chemistry and Physics 81st edition.CRCpess. ISBN 0-8493-0485-7, (2004).