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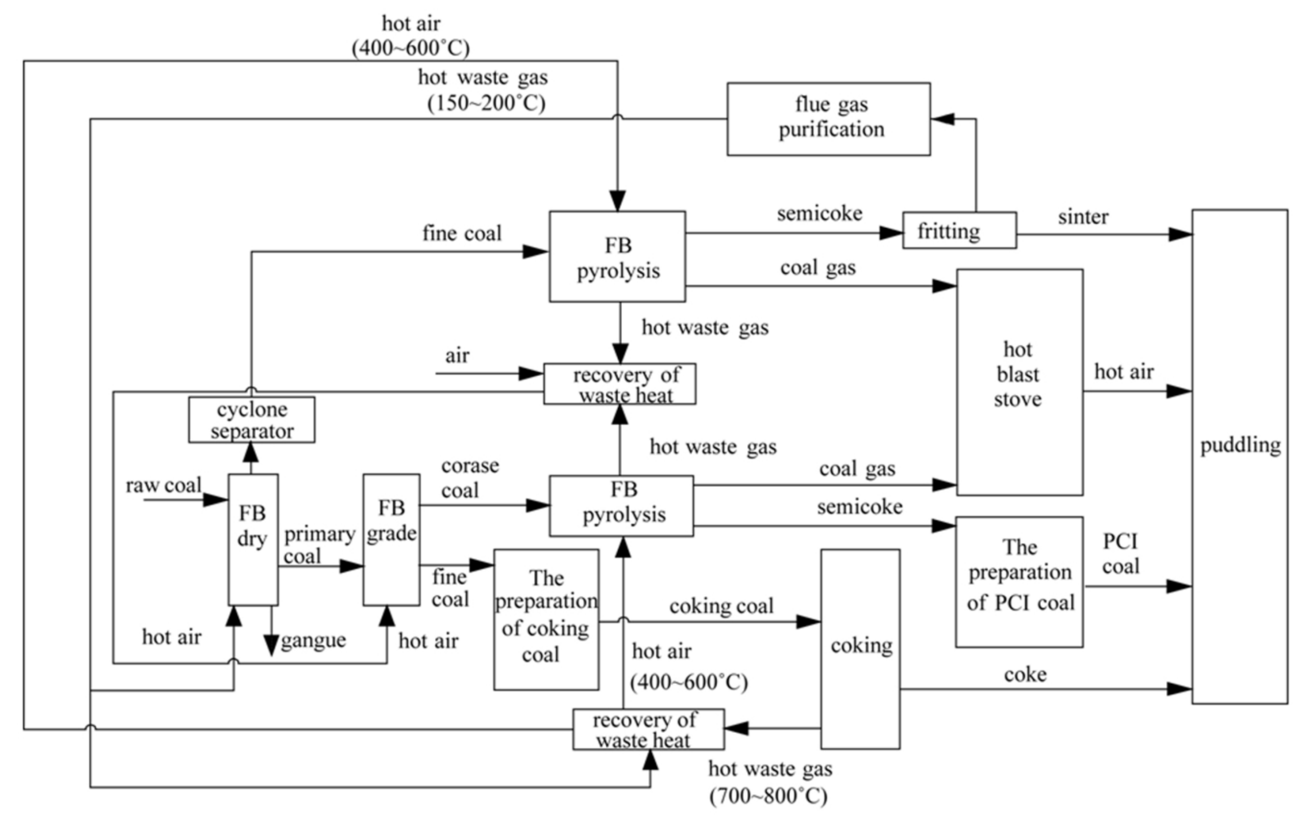

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The Technical Analysis on Upgrade and Coupling of Low-Quality Coal

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Abstract

Experimental study was conducted with regard to upgrading low-quality coal by low temperature pyrolysis technology and fluidization classification technology, which laid the theoretical foundation for research and development of low-quality coal upgrading process. Firstly, a pyrolysis pilot experiment of long-flame coal was performed and the optimum pyrolysis conditions were found. When the final pyrolysis temperature was 450˚C and the residence time was 10 minutes, the content of semicoke volatile dry ash-free was about 22.89% and the content of semicoke ash was about 16.1%. More than 5% of the ash needs to be removed before entering the pyrolysis fluidized bed. Thus, classification tests were carried out to pick out the coal particles with the target size of 500 μm, using a gas-solid fluidized bed coal picker. It was found that the separating effect of coal particles was the most satisfactory when the inlet velocity at the bottom was 3.27 m/s. The percentage of particles with diameters less than 500 μm was as low as 28.7% in the coarse samples. Based on the test results, a novel process of low-quality coal upgrade and coupling was proposed, which realized the sorting, grading, drying and pyrolysis of low-quality coal through the multi-stage fluidized bed integrated process.

Keywords

Low-Quality Coal, Low Temperature Pyrolysis, Fluidized Bed Particle Classification

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1. Introduction

Coal is a main product of China's energy consumption. Under the current energy situation, to develop coal clean

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technology and to improve the utilization of coal are of great significance to alleviate the pressure of the future energy. In 2012, China's total coal reserves reached 2298.9 tons. In the recoverable coal reserves, low rank coal accounted for about 40%. A plenty of coal in low rank coal has high impurity (high ash, high water and high sulfur) characteristics, which is called the low quality coal.

Li Zhen, Yu Wei, Yang Chao and Zhou Anning pointed out that the treatment of low rank coal slime is an effective way on basis analysis in the comprehensive utilization of low rank coal and coal slime [1]. Gu Xiaoyu had an experimental study on two kinds of Shenhua low rank coal of thermal modification qualitative processing researches. The results showed that the thermal modification could significantly improve the coal quality characteristic of low rank coal, eventually getting low moisture and high calorific value and improving the ignition quality of modified products [2]. The Chinese Academy of Sciences Institute of the Development Process of Coal Topping Process (BT process) which uses fast pyrolysis, rapid separation and rapid cooling realizes priority use of tar oil and gas and solid products such as carbocoal which is used to generate electricity [3]. In the 1970s, the rapid development of fluidized bed pyrolysis process for a variety of bituminous coal and lignite pyrolysis were researched by Australia's CSIRO. The reactor bed of circulating fluidized bed technology is composed by the grit with 0.3 - 1 mm. The residence time is short, and the energy from the flue gases of pyrolysis by the electric heater and the liquefied petroleum gas and nitrogen gas preheated air fuel formation [4].

This paper is based on low temperature pyrolysis and fluidized bed coal particles classification tests of fluidized bed. Based on the results, the process integrated design of multi-stage fluidized bed was provided for the sorting, grading, drying and pyrolysis of low-quality coal in the integrated iron system. On one hand, this design is conducive to complementary chiasma using of the waste heat in working procedures of iron making. On the other hand, the process integration design is in favour of the comprehensive utilization of low-quality coal. Furthermore, this new technology will reduce the cost of irons effectively, thus demand pressure of higher-order coal in steel industry will slow down.

2. Characteristics of Low Quality Coal

The main features of low-quality coal are high impurity. High impurity content will not only reduce the quality of coal, but also increase transportation costs and processing costs. If low-quality coal is directly used, it is easy to cause environmental pollution and energy waste. Taking sintering and coking as an example, with excessive moisture content, particularly with the high internal waters content in the coal, the water will break away from the surface of coal particles in the initial stage of accelerated warming, which is easy to cause the pores in the surface of coal particles ditch and even collapse and the sinter or coke exhibit more cracks. Then the mechanical strength of the product is reduced, and energy is more consumed during the heating process. Similarly, when the coal particles conduct to the liquid phase reaction by heating it, the higher ash content will impact the liquid flow resistance and reduce the bonding effect. While the mechanical strength of sinter and coke depends mainly on the full extent of liquid-phase reaction, the higher ash content will exacerbate pollution emissions. Since sinter and coke are both to enter blast furnace for iron making, the higher sulfur content will not only increase the sulfide emissions but also lead to the phenomenon of hot crisp iron. When dissolving in liquid iron in the form of ferrous sulfide, the sulfur will be enriched in the grain boundary in the solidification process, which will form low melting point eutectic, weaken the binding force between the grains and cause brittle cracking phenomenon.. For the elimination of low-quality coal high impurity process, preliminary mention quality treatment often cannot achieve the purpose of improving quality, but also requires combing the deep technology of quality, adjusting process reasonable, and using multi-stage processing means to achieve the ultimate upgrading.

In summary, to achieve efficient use of low-quality coal, it is necessary to carry out upgrading process from the source, that is, starting from the sorting and grading, not only to the reasonable control of component content in coal, but also on the particle size classification of coal particles to adapt to the needs of deep quality on low-quality coal.

3. Key Technology of Low-Quality Coal Upgrading

3.1. Low Temperature Pyrolysis

Using long-flame coal as pyrolysis experiment of coal, coal quality analysis results are shown in **Table 1**. As

Table 1. Analysis of test coal.

Analysis [%]	Value
Mt	19.5
Mad	11.8
Ad	17.07
Vdaf	37.53
FCdaf	62.47
Qnet,ar (MJ·kg^{-1})	18.83
Cad	56.53
Had	4.9
Oad	10.98
Nad	0.45
Sad	0.28

Mt is for total moisture; Mad is for inherent moisture; Ad is for dry base ash; Vdaf is for volatile content on dry ash free basis; FCdaf is for fixed carbon content on dry ash free basis; Qnet,ar is the net calorific power of as received basis; Cad is for air-dried basis carbon; Had is for air-dried basis hydrogen; Oad is for air-dried basis oxygen; Nad is for air-dried basis nitrogen; Sad is for air-dried basis sulfur.

can be seen from **Table 1**, the internal waters, volatile component and ash content are high. If we direct sintering or coking, it will reduce the coke strength. Meanwhile, because of higher volatile content of coal reduces the safety of production process, it also needs pre-removal. In summary, the coal used in the pyrolysis test program should be pre-dried to remove the remaining portion of the water to 5%.

The muffle furnace was used within the pyrolysis test, taking 1 g ± 0.0001 g of coal (diameter < 0.2 mm) placed in a crucible, then set the final pyrolysis temperature at 450˚C, 500˚C, 550˚C and 600˚C, respectively, residence time for 5 min, 10 min, 30 min, 50 min, 70 min and 90 min. Various conditions of semi-coke volatile content are shown in **Figure 1**, **Figure 2** is ash content of semi-coke.

From the analysis of **Figure 1**, with the improvement of terminal pyrolysis temperature, the energy obtained by the broken bonds the functional group increased and the rate of initial stage of devolatilization is increasing, the precipitation amount of volatiles is proportional to the final pyrolysis temperature. When the final pyrolysis temperature of 450˚C, the residence time is 10 min, the dry ash-free basis of semicoke volatile content is about 22.89%, which can meet the injection coal blending and general transport requirements of metallurgical coke. **Figure 2** shows that, with the final pyrolysis temperature increases, the corresponding increase in the ash content. In the general requirements, the coal ash content of metallurgical coking is less than 12%, sintering coal generally require less than 15%. When the final pyrolysis temperature is 450˚C, the residence time of 10 min, the ash content of semicoke is about 16.1%. Therefore, in the upgrading process design, it needs ash handling for coal before entering into pyrolysis fluidized bed. In summary, the optimum condition of pyrolysis fluidized bed upgrading: final pyrolysis temperature of 450˚C, the residence time of 10 min, remove more than 5% of ash before entering the pyrolysis fluidized bed.

3.2. Fluidized Classification

Gas-solid fluidized bed coal washer as the main body in the test equipment to conduct coal particle classification experiment research in a certain steel company. Tests mainly conducted on the effect of fluidization velocity on classification efficiency. Through the analysis of different conditions, the content of coal particle with its size less than 500 μm, in the lower refined coal to further determine the best classification conditions. The particle size distribution is shown in **Table 2**. The concentration distribution of particle size less than 500 μm is shown in **Figure 3**.

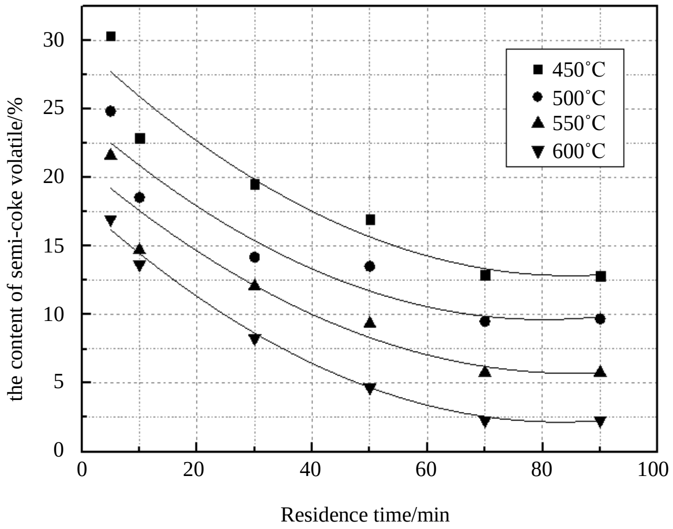

Figure 1. The content of semi-coke volatile under various conditions.

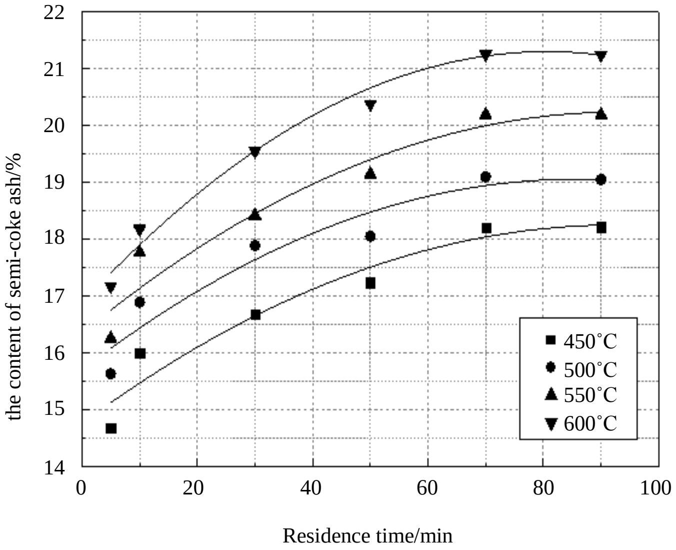

Figure 2. The content of semi-coke ash under various conditions.

Table 2. The initial parameter of coal particle size distribution in the experiments.

Particle size [μm]	Accumulative contents [%]
100	7.57
200	17.98
500	60.41
1000	72.61
2000	90.43
3000	100

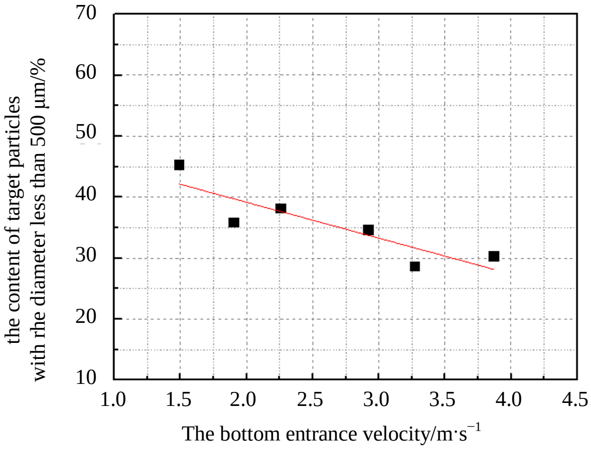

Figure 3. The content of particles with the diameter less than 500 μm under different bottom entrance velocity.

It can be seen from **Figure 3**, with the increase of fluidization velocity, the content of coal particle with its size less than 500 μm presents a descending tendency in lower refined coal. Classification has the best effect when the bottom entrance velocity is 3.27 m/s, the content of coarse coal particles the size less than 500 μm reduced to 28.7%.

4. Low Quality Coal and Iron the Quality Process

4.1. Identified Ideas of Upgrading in Low-Quality Coal

Accompanied by iron-making process, there have been migration and transformation of energy. And in the process of practical production, waste heat can be serious wasted, but the cause of this phenomenon is not just the quality of equipment and operational level. In order to further reduce the consumption, we should choose two points to analyze: one is the initial resource rationalization. It strictly controls the quality of materials which enter into the process system, especially the quality of coal, because coal, grain size and other factors will directly restrict the efficiencies of heat utilities. The other is rational process. On the basis of meeting the needs of normal production, the process should also take the heat recovery efficiency and continuity of coal preparation operations into account.

Our country has scarce water resources, only equivalent to 25% of the world's per capita, and regional distribution is uneven. The differences between North-South are larger. At the same time, the main coal-producing areas have less water reserves. For example, water resources of Shanxi, Gansu and Ningxia (autonomous regions) accounted for only 7.5 percent of the northern water resources and groundwater natural resources accounted for only 8.9% of the northern groundwater natural resources [5]. So, the dry coal preparation technology is more adapted to China's national conditions, not only for the promotion of industrialization, but also for the on-site processing of coal conversion.

Since the fluidization technology has large capacity and the advantages of coupling reaction and is convenient to transfer material, the coal upgrading devices are in fluidized bed as the main body, mainly including coal separation equipment and pyrolysis equipment. To further meet the coal upgrading operations, recycling different grade waste heat of sintering and coking processes will be useful for the pyrolysis of coal and dry.

4.2. Mention Recycling Process

Above all, a new kind of coupled low-quality coal upgrading process was presented (**Figure 4**). Based on the control for the low-quality coal sorting, grading, controlled drying and pyrolysis processes, the component content of the low-quality coal (such as low-grade bituminous coal and lignite) was done to achieve the sintering and coking targets. Upon completion of pulverized coal recovery, the goal of the low-quality coal replacing part of the high-quality ones was also achieved. It not only recycled the waste heat of the systems, but also improved the utilization rate of coal.

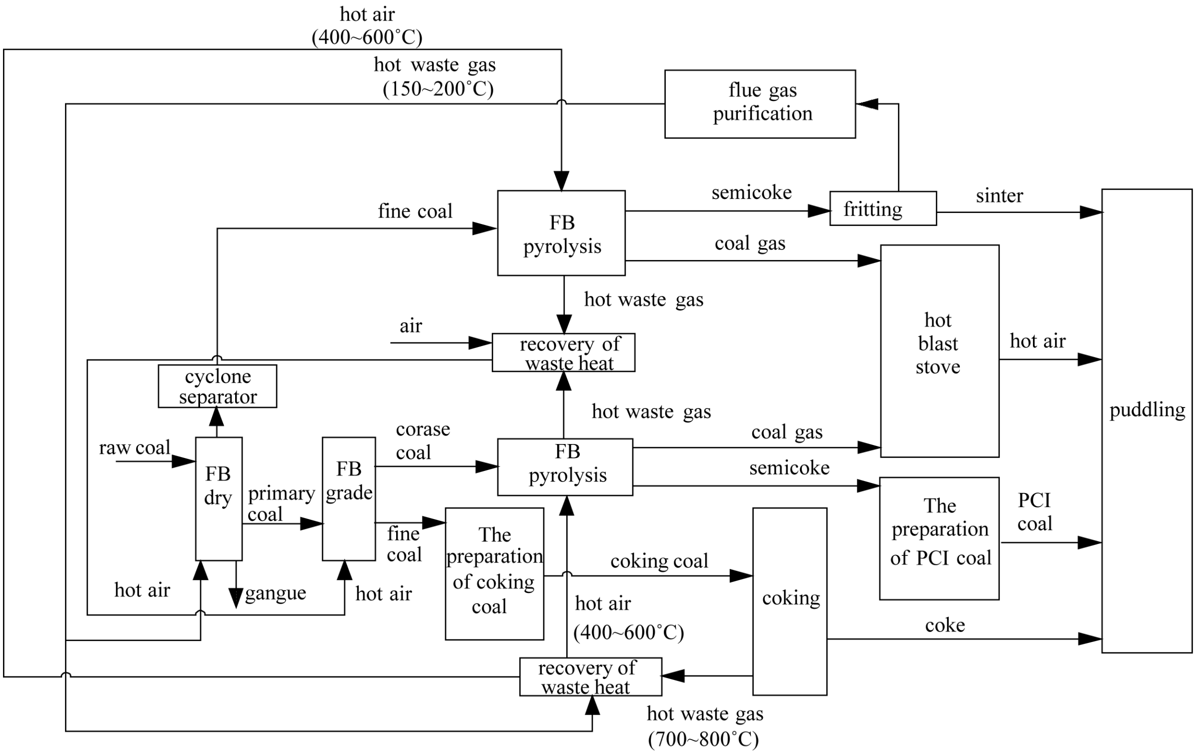

Figure 4. The system flow chart of low-quality coal upgrading.

Acknowledgements

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Dye-Sensitized Solar Cells Based on TiO_2 Nanoparticles Modified by Wet Milling

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Abstract

TiO_2 nanoparticles were produced from a commercial anatase powder through a wet milling process. The effect of grinding intensity, which is directly dependent on the operating parameters, was analyzed and the performance of polyethylene glycol (PEG400) as a dispersing agent in the milling system was also tested. The results showed that the processes using polyethylene glycol achieved a greater fragmentation of particles. This could be observed in the histograms made from SEM images taken from samples of powders from the processes, whose populations reached an average size of approximately 90 nm. The TiO_2 powders obtained by milling were then used in the manufacture of dye-sensitized solar cells. It was verified that the powders produced using the dispersing agent achieved the greatest efficiencies, the highest being 0.94%. The current produced by the cells proved to be very low compared to the voltages obtained which gave acceptable values up to 0.81 V.

Keywords

TiO_2 Nanoparticles, Wet Milling, Solar Cells

1. Introduction

Mechanical milling is considered to fall within the so-called "top-down" techniques [1], since it uses defragmentation from the collision between the grinding bodies (or grinding elements) and the dust particles to be grinded. This method has been attracting great interest for the study of nanoparticle formation [2]-[5] since it is highly feasible from a technical and economic perspective because of simplicity of the process [6]. This paper applies this technique to titanium dioxide TiO_2, a material of great technological interest at present and which has many applications in various fields ranging from photovoltaics and photocatalysis to electrochromism and gas sensors [7], because of its exceptional electrical, optical and physical-chemical properties [8]. The particular application, which is assessed in this paper, is the development of dye-sensitized solar cells, in which TiO_2 is the

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semiconductor most widely used for this type, because it produces the best results [9]. This technology has become very significant in recent years because it presents as an important alternative for the world's current energy requirements. Thus, in order to see which contributions the product obtained can provide for this technology, efficiency results of solar cells developed from the post grinding powders are presented.

2. Experimental

2.1. Milling Process

2.1.1. Equipment

The milling experiments were carried out in a bead mill with a horizontal stirrer manufactured by NETZSCH which operates according to a multiple steps circular system. The milling chamber has a volume of 0.5 L and is horizontally oriented. The stirrer shaft consists of a horizontal cylindrical hollow shaft equipped with equidistantly fixed drivers. Both the stirrer and the surface covering the chamber are made of polyurethane. The chamber has a 0.15 mm opening internal sieve which keeps the beads within the chamber. A pump of "progressive cavities" is in charge of driving the suspension throughout the entire cycle. A series of pipes is responsible for driving the suspension from the pump outlet to the milling chamber and from the chamber outlet to the stirring tank to restart the cycle.

2.1.2. Materials

The material to be grinded is a commercial titanium dioxide powder of high purity (99%) purchased from the CIATEX Company. The dispersing agent used was polyethylene glycol 400 [$HO(C_2H_4O)_nH$] and was purchased from the Merck Company. The microspheres used as grinding media provided by NETZSCH are made of yttrium stabilized zirconium dioxide (ZrO_2:Y), with an average diameter of 0.25 mm and a density of 3852 kg/m^3.

2.1.3. Milling Parameters

A total of four milling processes were carried out as it is shown in **Table 1**. The processes can be divided into two groups, those that do not use the dispersing agent (NP1 and NP2) and those that do use it (SP1 and SP2).

2.2. Manufacture of Solar Cells

A paste of TiO_2 powder was prepared from a suspension in ethanol at 25% weight, and this was put on a conducting glass (substrate) forming a layer in a small defined area of 5 mm × 5 mm. Then, the substrate with the TiO_2 layer was subjected to a heat treatment at 450˚C for 45 minutes. It was then sensitized by immersion in a solution of N719 standard dye ($C5_8H_86O_8N_8S_2Ru$) for approximately 14 hours. Platinum was put in another conductive glass substrate, using an ethanol solution of chloroplatinic acid and a heat treatment of 15 minutes at 450˚C; this substrate was used as a counter electrode. The cell was assembled by adding a few drops of electrolyte $\left(I^-/I_3^-\right)$ on the colored film and closing it with the counter electrode. At the ends of both substrates silver paint was used for a better contact.

Photoresponse

The assessment of the assembled cell was performed in an experimental system in which a dichroic lamp of 50W was used as light source. The incident light passed through a tray containing water as an IR filter. The cell was placed in such a way that light is incident first on the working electrode, and then passes through the electrolyte and ultimately, the platinized glass. The relationship between the current I and the voltage V, which is

Table 1. Experimental conditions of every milling process.

Milling process	TiO_2 lead (% w/w)^a	PEG concentration (% v/v)^a	Stirring speed (rpm)	Milling time (min)
NP1	3	0	1375	240
NP2	10	0	2375	60
SP1	3	0.5	1375	240
SP2	10	0.5	2375	60

[a]. Related to destilled water.

generated by the cell, is determined by the variation of resistance in the external circuit. The recorded data are presented in curve V-I along with the corresponding power curve.

3. Results and Discussion

3.1. X-Ray Diffraction of TiO_2 Nanopowders

The diffractograms for the commercial TiO_2 powder (unground) and the powders obtained after each milling process are shown in **Figure 1**. Diffraction patterns keep the characteristic peaks of the starting powder corresponding to the anatase phase. This clearly shows that the wet milling, regardless of the parameters used in the process, does not change the initial structure of the anatase powder used as raw material. With the milling, a number of defects and local stresses which are typical of this process and cause a decrease in the size of the crystal grain are produced in the material structure. This effect can be seen in the reduction of intensity of the diffraction peaks after each milling process, being more evident in the greater intensity milling processes (NP2 and SP2).

Figure 2 and **Figure 3** show the change of crystal grain size during each milling process. These sizes were

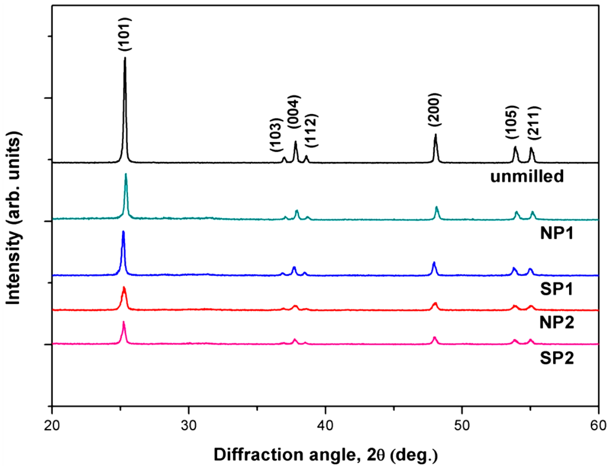


Figure 1. XRD patterns of anatase powders, before and after the milling process according to **Table 1**.

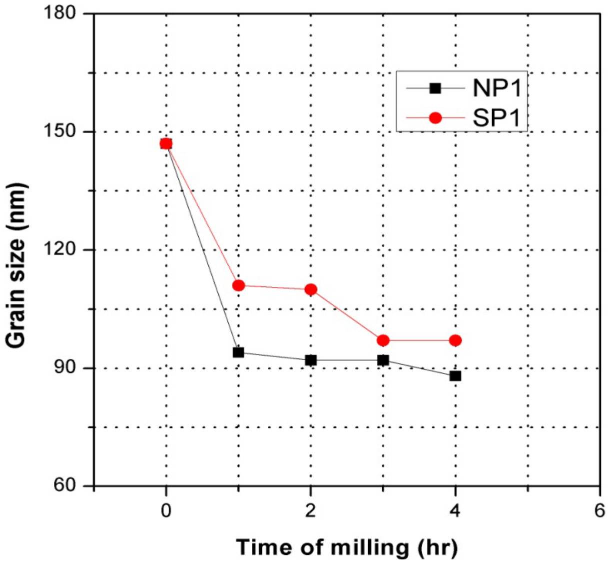


Figure 2. Grain size vs. Time of milling of TiO_2 powders made from 3% w/w of TiO_2 load at 1375 rpm, until to 240 minutes of milling and PEG.

obtained using the Rietveld refinement method [10] from samples taken at different intervals of time. The results show that the decrease in grain size is very fast and there is a tendency to reach a threshold size similar to an exponential decay. This trend is observed mostly in the NP1 process, when after the first hour the grain size has already reached a limit value of about 90 nm.

3.2. Scanning Electron Microscopy and Histograms of Particle Size Distribution

The micrographs taken from the dust samples, both before and after the four milling processes, are presented in **Figure 4** and **Figure 5**. The particles obtained after each milling process have an irregular shape and size range. Furthermore, an increased agglomeration of the particles resulting from the NP1 and NP2 processes becomes noticeable; these processes did not use the dispersing agent.

Using the image analysis program "Image-Pro v. 4.1", particle diameter information was taken from the micrographs displayed, obtaining the size distribution histograms that accompany each image. The adjustment of the histograms (continuous red line) for each size distribution was performed by a Log-Normal function from

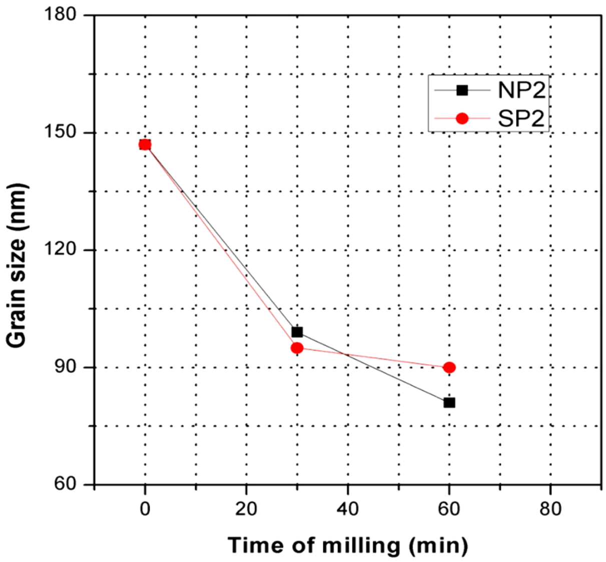


Figure 3. Grain size vs. Time of milling of TiO_2 powders made from 10% w/w of TiO_2 load at 2375 rpm, until to 60 minutes of milling and PEG.

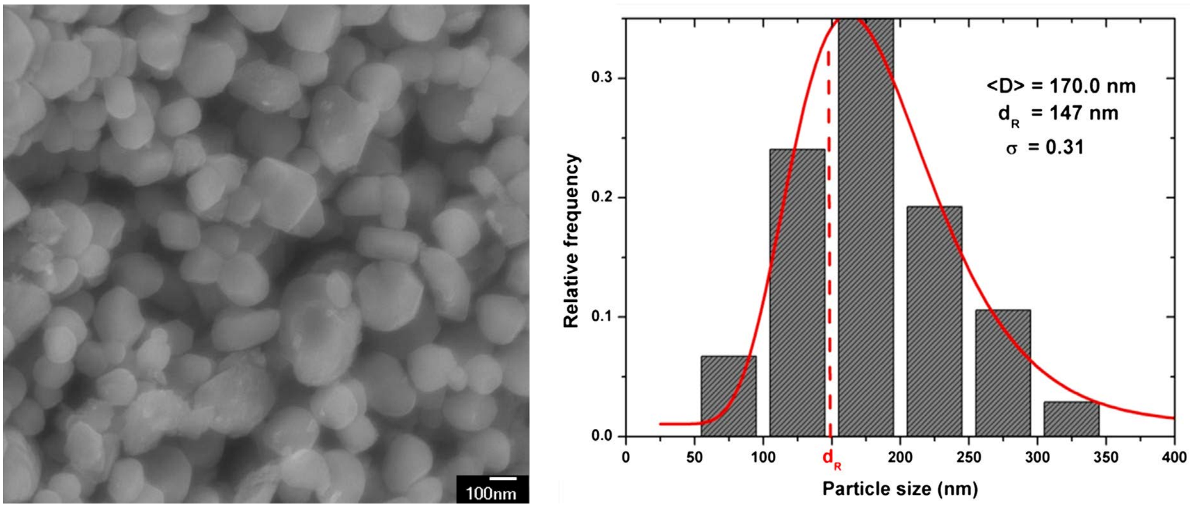
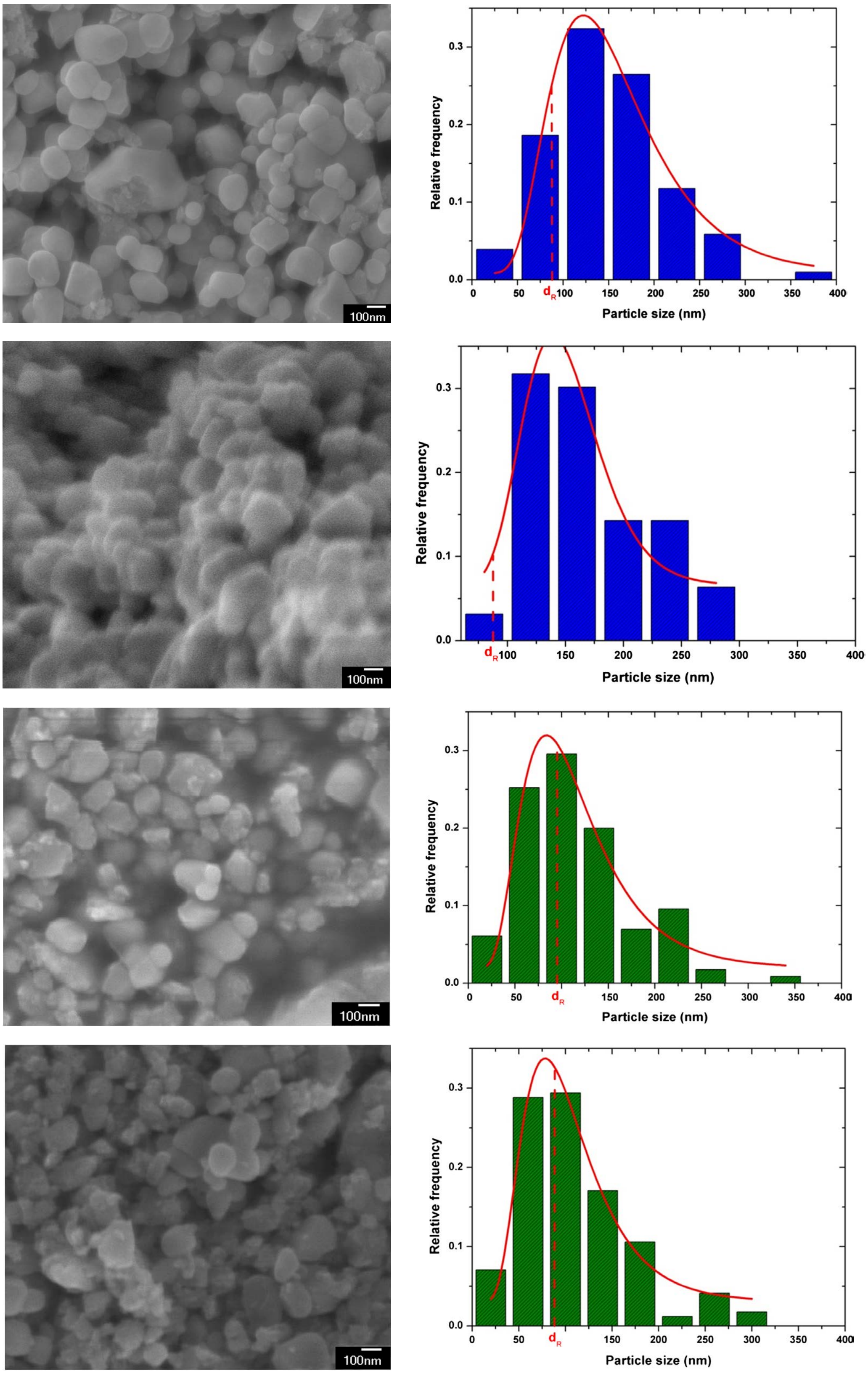


Figure 4. SEM picture of Anatase particles before milling and its particles size distribution.



NP1

3% w/w TiO_2
1375 rpm
240 min

<D> = 133.6 nm
d_R = 88 nm
σ = 0.42

NP2

10% w/w TiO_2
2375r pm
60 min

<D> = 142.8 nm
d_R = 81 nm
σ = 0.23

SP1

3% w/w TiO_2
0.5% v/v PEG
1375 rpm
240 min

<D> = 93.5 nm
d_R = 97 nm
σ = 0.47

SP2

10% w/w TiO_2
0.5% v/v PEG
2375 rpm
60 min

<D> = 86.5 nm
d_R = 90 nm
σ = 0.46

Figure 5. SEM pictures of the TiO_2 particles after the four different milling process. Right, the corresponding particles size distribution.

which the average value $\langle D \rangle$ from the distribution and the standard deviation σ were taken. The values obtained are presented in **Table 2**. For comparison purposes in each of the histograms presented, the crystal grain size d_R obtained from the Rietveld refinement method is indicated.

The results show that in the SP1 and SP2 processes, where the dispersing agent was used, a greater particle population was reduced reaching values of an average size of 93.5 nm and 86.5 nm, respectively. Instead, in the NP1 and NP2 processes where no dispersing agent was used, the decrease in size was somewhat poor, as it is shown by their average size values of 133.6 nm and 142.8 nm, respectively. On the other hand, these values also show that increasing the intensity of milling did not cause an effective decrease in the particle population. Thus, we can say that the most influential factor that contributes to the reduction of the particle size is the use of the dispersing agent

It is also observed that after the NP1 and NP2 milling processes, the average particle size of each process continues to be greater than their respective grain sizes, which are smaller this time because of the grinding. It is in the SP1 and SP2 processes where we find that the values of average particle size and grain size are almost the same. The cause can be attributed again to the dispersing agent used in both processes, which had precisely the task of breaking up particles, something which was not achieved in the first two processes in which the dispersing agent did not participate.

3.3. Characteristic Current-Voltage Curves of Solar Cells

Solar cells made with the powders obtained from the four milling processes responded in the way shown in **Figure 6**. The curves shown correspond to the best results achieved for each type of powder. For the efficiency estimates η, the ratio between the maximum power obtained $P_{\max}$ and the incidental radiation power P_{in} was used, which in all cases was 1000 W/m^2. The efficiency values with the most significant parameters that determine it are shown in **Table 3**. A cell with the initial commercial powder was also made, but it had no response to radiation. Its bigger particles impeded a good dye impregnation and, therefore, the photon adsorption was poor.

The solar cells made from the powders after milling reached good voltage values ranging from 0.74 V to 0.81 V. However, the values obtained from short circuit current were still very low, being below 0.55 mA, like the form factor with values between 0.54 and 0.59. This indicates that there was not a good transport of electrons in the cells circuit. This is directly related to the structure of the film formed. The presence of agglomerated particles particularly in cases where there was no dispersing agent, and additionally the presence of large particle sizes reduce the effective area through which electrons can move. Moreover, the high stress experienced by the particles during milling generates defects in them, which cause charge dispersion and reduce their mobility. A consequence of all this is that there are electrons that are unable to overcome the difficulties of the material and have to recombine with the oxidized dye without achieving the cell circuit.

The best efficiencies were achieved by the cells manufactured with the powders and in whose manufacture the dispersing agent was used. Coincidentally, the smaller particle sizes were achieved for these processes. Additionally, after the heat treatment performed for the manufacture of the electrodes of solar cells, porous films were obtained due to the space left by the molecules of the dispersing agent. This contributed to a greater effective area that favored both the adsorption of the dye molecules and the mobility of the electrons.

4. Conclusions

Titanium dioxide nanoparticles were obtained with a broad size distribution from a commercial anatase powder

Table 2. Particle size distribution of milling particles fitted by Log-Normal equation.

Process	Average (nm) <D>	Standard deviation σ
Before milling	170.0 ± 4.6	0.31
NP1	133.6 ± 6.6	0.42
NP2	142.8 ± 8.2	0.23
SP1	93.5 ± 7.3	0.47
SP2	86.5 ± 6.1	0.46

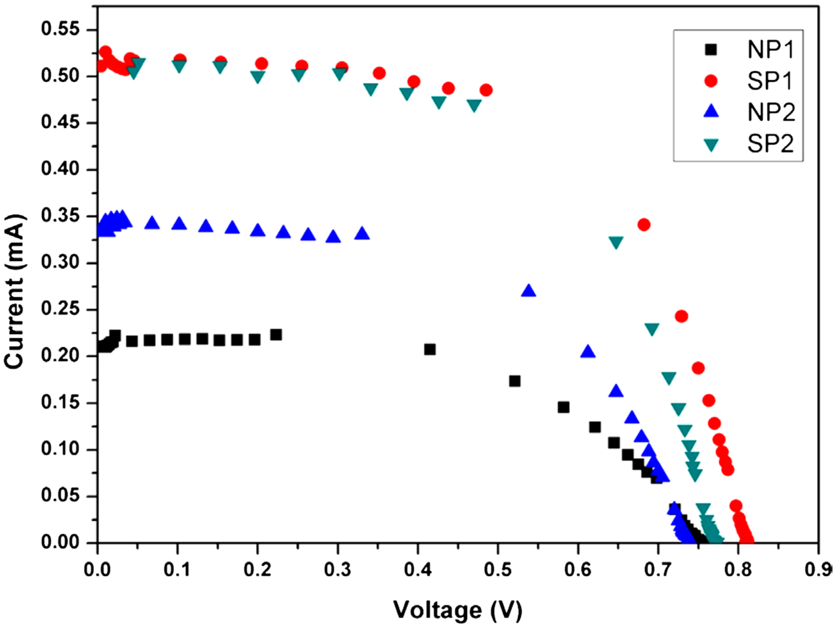


Figure 6. Current-voltage curves of DSC cells based on the powders from the different milling.

Table 3. Photovoltaic performance of DSC of different milling TiO_2 samples.

TiO_2 powder	V_{OC} (V)	I_{SC} (mA)	FF	η%
NP1	0.79	0.21	0.54	0.36
NP2	0.74	0.33	0.59	0.58
SP1	0.81	0.51	0.57	0.94
SP2	0.77	0.52	0.55	0.88

by an alternative method such as wet milling which could be the basis of a mass production process.

The wet milling process, regardless of the parameters used, reduced the grain size of the powders up to a maximum threshold value of about 90 nm, which is reached after about the first hour of milling.

The use of the dispersing agent (PEG400) in the milling system proved to be an important factor in achieving smaller particle sizes. This allowed obtaining average particle size values of 86.5 nm and 93.5 nm in the two processes that used the agent. Increasing the grinding intensity did not make a greater contribution for the fragmentation of the particles.

The use of the dispersing agent also helped to achieve the best efficiencies in the solar cells developed. Efficiency values of 0.94% and 0.88% were obtained in the cells which used powder films from the processes using the dispersing agent.

Acknowledgements

My special thanks to professors Alcides López (InstitutoPeruano de Energía Nuclear, Lima) and Francisco Paraguay (Centro de Investigación en Materiales Avanzados, Mexico) who contributed with the necessary characterizations for the development of this paper.

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Composition Characteristics of Gas Hydrate Produced Gas and Pretreatment Research

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Abstract

To accelerate the pace of research and the use of alternative energy strategies Gas Hydrate, on the basis of previous studies, this paper analyzes the composition characteristics of Gas Hydrate produced gas. It provides technical support for our research and the use of Gas Hydrate. This eases the supply and demand of energy and reduces pollution of the atmospheric environment.

Keywords

Gas Hydrate, Gas Composition, Pretreatment Process, Technical Support

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1. Introduction

Gas Hydrate is recognized as one of the world energy to succeed in nature, which has important strategic significance and enormous economic value. It is included in the key research topics in many developed and developing countries. Once the Gas Hydrate was successfully mined, research of ground gas processing technology will have great significance. Analysis of the produced gas composition characteristics can not only provide important information about Gas Hydrate accumulation mechanism, reserves, mineral scale, but also promote the progress of Gas Hydrate produced gas and other related ground pretreatment processes.

This paper will summarize combustible ice produced gas geochemical data and analysis and testing technical information, and then the gas composition of Gas Hydrate can be determined. Depending on the composition of Gas Hydrate, the pretreatment technology can be systematically studied, so that it can provide the ground support systems of Gas Hydrate produced gas a reference.

2. Distribution of Resources and Reserves of Gas Hydrate

Gas Hydrate is made from water and gas under the conditions of low temperature and high pressure. It is similar

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to ice, non-stoichiometric and crystalline clathrate compounds. Gas Hydrate is called "combustible ice" and "solid gas" because its appearance is very similar with ice or solid alcohol, and it is easy to be ignited. Under standard conditions, a unit volume of Gas Hydrate can store 160 to 180 per unit volume of natural gas. It is a new energy-efficient with a high energy density and it is shallow, large-scale and clean, etc. Therefore it is called the strategic resources that have the most promising commercial development in the 21st century.

2.1. The Distribution of Gas Hydrate

There are very rich reserves of Gas Hydrate on Earth. About 27 percent of the land (mainly in the freezing rock) and 90% of the sea all contain Gas Hydrate. The following two areas are most likely to form it:

1) High-latitude land (tundra) and the continental shelf. Gas Hydrate on land exists in the place that is in the depth of 200 - 2000 m. It is mainly distributed beneath the permafrost of the high-latitude polar or at the edges of continental slopes and ridges, where the temperature is very low. Area of global polar permafrost regions is about 1.1×10^7 km^2, of which the area of Qinghai-Tibet Plateau is about 1.588×10^6 km^2.

2) Seabed. It is generally believed that when the depth of water is more than 500 m, the temperature and pressure of seabed sediments will be able to meet the formation conditions of Gas Hydrate. Gas Hydrate in the sea is mainly present in the island slope, mainland slope and on the surface sediments or sedimentary of the basin.

Currently, combustible ice is mainly distributed in the following locations:

1) The Bering Sea in Western Pacific, Okhotsk, trench of Kuril, Okinawa trough, the sea of Japan, trough of Japan Shikoku, Indonesia Sulawesi sea, Australia's north west sea and New Zealand's north island off the coast.

2) The east Pacific Ocean trough in China and the United States, in northern California offshore in Oregon, Peru trough.

3) Blake ridge outside waters of the Atlantic on the east coast of the United States, the gulf of Mexico, the Caribbean.

4) The Indian Ocean of the Oman gulf.

5) The deep lake.

6) The polar regions, such as the arctic Barents sea and Beauport sea, Antarctica's Ross sea and Weddell sea.

7) Mainland permafrost regions, such as Russia's Siberia, the Tibetan plateau in China.

2.2. Reserves of Gas Hydrate

Makogon indicated that there was Gas Hydrate in the permafrost within the territory of Russia, since then there has been two quite different views about the reserves of Gas Hydrate. One view is that: considering the dispersion and difficult exploitation of Gas Hydrate, the existence of gas hydrates can be ignored. Another argument is that: in the permafrost on the earth (27% of the land area) and thermal stability of the sea area (90% of the sea area), the hydrate is widespread and should not be neglected. In the recent 30 years, research of scholars from all over the world on the global Gas Hydrate resources generally can be divided into three stages: the 1970s to the early 1980s (1017 - 1018 m^3 level), the late 1980s to the early 1990s (1016 m^3 level), since the late 90s of the twentieth century to date (1014 - 1015 m^3 level). Through the analysis we found that the earliest estimated results are bigger 2 - 3 orders of magnitude than that of today. Resource estimate value for Gas Hydrate with the change of time is shown in **Figure 1**.

Despite there is big differences in the global estimate value of Gas Hydrate resources, Now scientists from all over the world are more consistently agree with that its resources is 2×10^{16} m^3. If the reserves are converted into organic carbon of the earth's resources, it will account for more than half of the global total organic carbon. Therefore, as a potential energy, Gas Hydrate undoubtedly has great appeal. **Table 1** shows the estimates of the amount of combustible ice in the oceans and permafrost.

According to the current level of exploration of combustible ice, identifying long-term resources to the amount of resources geology, geological reserves, and proven reserves will take some time. But what is certain is that, compared with conventional gas reserves of natural gas, combustible gas resource will great influence on the structure of energy in the future.

Compared with conventional natural gas reserves, the amount of Gas Hydrate of potential resources will have a huge impact on the future energy structure.

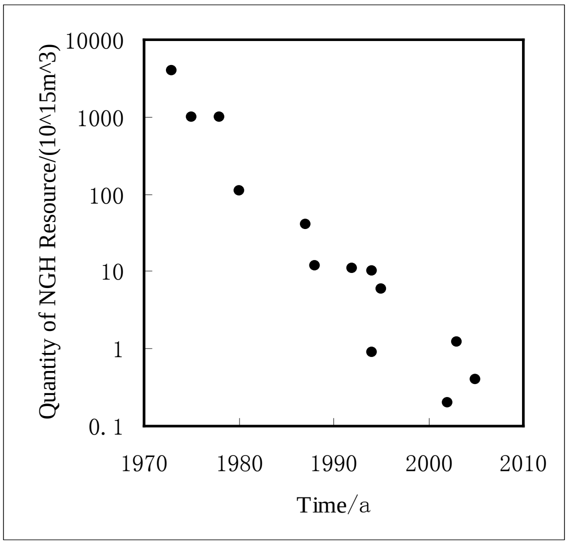


Figure 1. Resource estimation of Gas Hydrate in different periods.

Table 1. Estimates of Gas Hydrate in nature reserves.

Permafrost hydrate	Marine hydrates/m^3	References
5.7×10^{13}	$(5.25) \times 10^{15}$	Trofimuk (1977)
3.1×10^{13}	3.1×10^{15}	Melver (1982)
3.4×10^{16}	7.6×10^{18}	Dobrynin (1981)
1.4×10^{13}		Meyer (1981)
1.0×10^{14}	1.0×10^{14}	Makogon (1981)
	1.8×10^{16}	Kvenvolden (1988)
7.4×10^{14}	2.1×10^{16}	MacDonal (1990)
	$(2.6 - 13.9) \times 10^{16}$	Gornitz andFung (1994)
	0.38×10^{15}	Ginsburg and Soloviev (1995)
	$(0.38 - 1.0) \times 10^{15}$	Soloviev (2002)

3. Composition Characteristics of Produced Gas

The data in **Table 2** are the range of gas molecules and isotopic composition of Gas Hydrate in the following areas: Oregon coast [1], Vancouver island, Costa rice inshore coastal Sakhalin island, South Korea, the east China sea, Japan near shore, offshore, the Norwegian sea, gulf of Cadiz, Gabon, the gulf of Mexico shoreline, south Carolina, near shore, black sea, the sea of Marmora, the eastern Mediterranean, Alaska and Canada McKenzie and China Qinghai [2], etc.

From **Table 2**, it is not difficult to find that, gas molecules of Gas Hydrate existing in the nature mainly include C_1, C_2, C_3, I-C_4, n-C_4, I-C_5, n-C_5, neo-C_5, cycl-C_5, n-C_6 and its isomer hydrocarbon gas molecules, and the conventional gas such as CO_2 and H_2S molecular, then even some complex hydrate contains C_6+ or C_7 - C_9 heavy hydrocarbon molecules. In a word, all the characteristics of gas molecules can be roughly divided into two categories: one type of gas is composed mainly of methane ($C_1 > 99.9\%$), containing a small amount of C_2 and C_3; range of another type of gas is wide, containing C_1 - C_6+ paraffin, CO_2 and H_2S, etc.

3.1. Composition Characteristics of Marine Gas Hydrate

179 copies (Atlantic 73, Pacific 106) were published between 1999 and 2011 about gas molecules and isotopic

Table 2. The content range of Gas Hydrate gas molecules and the isotopic composition.

The gas composition	Composition range of molecular
C_1	46.01% - 99.999% (n = 230)
C_2	0.00% - 15.37% (n = 230)
C_3	0.00% - 21.05% (n = 230)
n-C_4	0.00% - 9.50% (n = 221)
i-C_4	0.00% - 5.66% (n = 207)
n-C_5	0.00% - 0.90% (n = 110)
i-C_5	0.00% - 1.49% (n = 112) 36.01% (n = 1)
neo-C_5	0.00% - 0.20% (n = 24)
cycl-C_5	0.00% - 0.024% (n = 13)
n-C_6	0.00% - 0.22% (n = 18)
C_6^+ or C_7 - C_9	0.00% - 1.85% (n = 18)
CO_2	0.00% - 27.63% (n = 105)
H_2S	0.00% - 2.20% (n = 90)

n: Statistic number of the sample.

composition data of worldwide submarine Gas Hydrate sample. Marine Gas Hydrate mainly exists in the depth of 390 - 3306 m, some exists on the surface of sea bottom; others exist in the 330 m below the seabed. Gas molecules of marine Gas Hydrate mainly include C_1, C_2 and C_3, I-C_4, n-C_4, I-C_5, n-C_5, neo-C_5, C_1 - C_5 hydrocarbon gas molecules and carbon dioxide (CO_2), hydrogen sulfide (H_2S), and other inorganic gas molecules. And most molecules are mainly methane hydrate whose content is greater than 99%, other component content is lower, Vancouver island offshore Barkley canyon, Green valley of the gulf of Mexico, the Mississippi valley and Atwater canyon hydrate contains higher content of C_2 - C_5. However, at present there are few reports that marine Gas Hydrate contains high molecular weight components such as C_6 - C_7. Only Lu (2007) measured that the hydrate samples contain high content of C_6 - C_7 in the Barkley Canyon, and at the same time proved that there is H structure hydrate in the samples [3].

3.2. Composition Characteristics of Gas Hydrate in Inland Sea and Lake

According to 35 copies of data from gas molecules and isotopic composition of Gas Hydrate in inland seas and lakes between 1999 to 2011, it is discovered that natural Gas Hydrate of Inland sea and lake exists 667 - 2050 m in depth. The depth of sample in sea bottom was relatively shallow, between 0.11 m and 7.15 m. Inland sea and lake is rich in natural gas hydrate, containing C_1 - C_9, CO_2, etc. but H_2S components are not checked out. C_1 content in the sample is more than 95%, and other content of components is lower, but individual abnormal C_5 content in natural Gas Hydrate samples is as much as 36.01% in the Sea of Marmara [4].

3.3. Composition Characteristics of Terrestrial Permafrost Gas Hydrate

According to 30 copies of data from gas molecules and isotopic composition of Gas Hydrate in terrestrial permafrost from 1999 to 2011, it is discovered that there is little Gas Hydrate in terrestrial permafrost. The buried depth of Gas Hydrate is deep (134 m - 134 m), and molecular species is relatively more, containing C_1 - C_6+, CO_2, etc., but H_2S components are not checked out.

4. Pretreatment Process

The process of natural gas processing is necessary when it is separated from the oil and gas field separator. Then natural gas is allowed to enter distribution pipe after processing. So this is a very significant component of natural gas industry. The pretreatment process of Gas Hydrate produced gas can consult the existing gas treatment process, as shown in **Figure 2**.

It should be emphasized that not all of the gas experiences the process in **Figure 2**. For example, if the acid component content in the produced gas is very small, which is already in line with the quality index of the natural gas commodity, it is not necessary to remove the acid gas. If ethane and heavier hydrocarbons in produced gas components are very few, the produced gas can be directly turned into liquefied natural gas (LNG) after pretreatment, etc.

According to composition of Gas Hydrate, pretreatment process is mainly divided into acid process and dehydration process.

4.1. Desulfurization Processes of Gas Hydrate Produced Gas

Desulfurization methods of Natural gas can generally be divided into chemical solvent method, physical method, chemical solvent-physical solvent method, direct conversion and other types. Amine method (**Figure 3**) is the main gas desulfurization technology. Different solution with MDEA as main ingredients is a good natural gas desulfurizer.

Under the control of economic factors, compared with the amine method + Claus + SCOT traditional crafts, direct catalysis and biological desulfurization method is technology for low sulfur gas desulfurization and sulfur recovery. The biological desulfurization method is alternative desulfurization technology for low sulfur gas.

4.2. Dehydration Process Gas Hydrate Produced Gas

Natural gas dehydration refers to removing water vapor from natural gas or removing dissolved water from natural gas condensate (NGL). The purposes of the dehydration are: 1) Prevent the occurrence of gas hydrates and

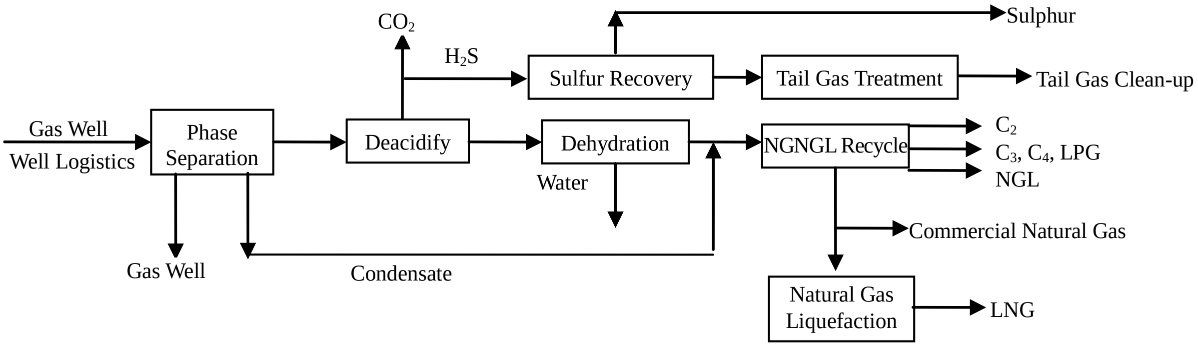
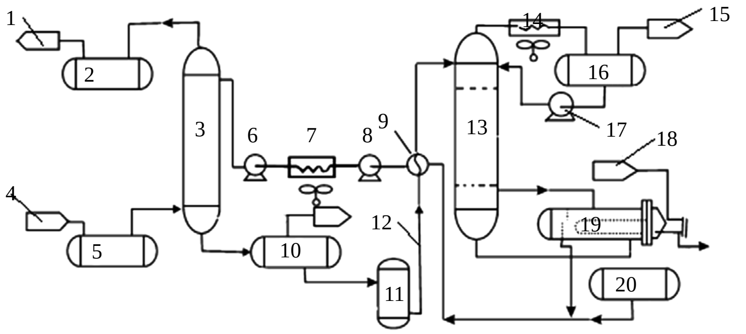


Figure 2. Schematic diagram of natural gas process.



1—clean gas; 2—clean gas separator; 3—absorption tower; 4—sulphur—bearing gas; 5—feed gas separator; 6—alcohol amine solution pump; 7—solution cooler; 8—booster pump; 9—lean—rich solution heat exchanger; 10—flash tank; 11—filter; 12—flash steam; 13—regeneration tower; 14—overhead condenser; 15—sour gas; 16—backflow collecting cans; 17—backflow pump; 18—heat source; 19—reboiler; 20—buffer tank.

Figure 3. The basic technological process of amine system [5].

liquid water in the process of handling, storage and transportation. 2) Make it conform to the water content index of the products of natural gas. 3) Prevent corrosion. Therefore, the process of dehydration is needed in the natural gas dew point control (or deoiling dehydration), gas condensate recovery, liquefied natural gas (LNG) and compressed natural gas production. The dehydration methods of natural gas include absorption method, adsorption method, low temperature method, membrane separation, gas steam formulation and distillation etc.

5. Conclusions

1) Gas compositions of marine Gas Hydrate mainly include C_1 - C_5 hydrocarbons, CO_2 and H_2S, less C_6+; Inland sea and lake is rich in natural gas hydrate, containing C_1 - C_9, CO_2, etc. but H_2S components are not checked out.; There are also many gas compositions of terrestrial permafrost Gas Hydrate: mainly C_1 - C_6 hydrocarbons, CO_2, H_2S components are not checked out. According to the composition of methane carbon isotope, it shows that, marine Gas Hydrate < Gas Hydrate in Inland sea and lake < Composition characteristics of terrestrial permafrost Gas Hydrate.

2) According to the different gas composition, the ground treatment system of Gas Hydrate produced gas for the decomposition gas can be different. When there is less acidic ingredient, desulfurization process is not necessary. When acidic component is large, it not only needs the process for acid treatment but also the process for sulfur recovery.

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Transmission and Consumption of Air Power in Pneumatic System

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Abstract

In recent 20 years, energy saving has been done in many projects. However, in pneumatic system, it is not easy to determine or measure the air power flow because of the compressibility of pneumatic system. In this paper, we used air power meter (APM) to measure the energy consumption of flow in pneumatic cylinder actuator system. Meter-in circuit and meter-out circuit of speed control system are used in this research. The model of cylinder system is based on four equations: state equation of air, energy equation, motion equation and flow equation. The model estimates the pressure change in charge and discharge side of cylinder, and also the displacement and velocity of the piston. Furthermore, energy consumption could theoretically be calculated when the change of air state is regarded as isothermal change. Lastly, some data of these two circuits are shown, and the consumption of energy is discussed.

Keywords

Air Power, Meter-In Circuit, Meter-Out Circuit, Energy Consumption

1. Introduction

Pneumatic cylinder actuator is widely used in factory automation field as a driving machine. To compare with the electrical motor, it is commonly used for conveying system because of its advantage of reciprocal linear motion. Furthermore, in meter-out circuit, the most remarkable characteristic is the response of speed control becomes stable easily when adjusting the speed control valve. Recently, PTP (Point To Point) is a representative application in the industry field. In these ten years, the development of pneumatic technology has become better due to the widely use of the pneumatic cylinder.

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As we know, the power of compressed air used for mechanical work is based on the electricity consumption of compressor. The energy saving in pneumatic system is important. So many methods had been proposed [1]. In order to achieve the effective use of available energy, the assessment of energy consumption is necessary. Previous research showed that the available energy of air consists of two parts: power transmission energy and expansive energy [2]. It is clarified that over half of supplied available energy is used and remaining energy is lost [3]. However, the measurement of the consumption of available energy in a pneumatic cylinder system has not been conducted. The reason is that there are not any effective methods to measure the energy. To compare with the traditional energy consumption assessment method based on air flow rate, a new method using air power in terms of available energy has been proposed [4]. With air power, mechanism and factors will make objective of energy savings clearly.

In this paper, we use APM (Air Power Meter) to measure the energy consumption of the pneumatic cylinder based on meter-in and meter-out circuit, and the experimental results will be discussed.

2. Circuit of Speed Control

In general, the speed control of the pneumatic cylinder is controlled by a speed-control valve which is consisted of a variable throttle valve and a check valve. In term of the adjustment of the charging or discharging flow when using the speed-control valve, the meter-in and meter-out circuit have the different characteristics. As shown in **Figure 1**, the meter-in circuit could control the speed of the pneumatic cylinder by varying the charging flow. **Figure 2** is a schematic of meter-out circuit which is controlled by varying the discharging flow. To compare with the meter-out circuit, meter-in circuit has two advantages as follows. Assume that these two circuits are driven in the same conditions of the supply pressure and load mass. One advantage is the miniaturization of machine and another one is the less consumption of air.

However, meter-out circuit is more popular than meter-in circuit. Many pneumatic mechanism makers recommend people to use meter-out circuit expect for the particular situation. We consider that the reason is the simplification and stability of the speed control. The simplification indicates that the setting of speed is easily because of the speed is proportional to the regulated size of the speed-control valve. And the stability indicates that the speed response is not relevant to the load mass. That is, the speed response reaching to steady-state is independent on the change of load mass.

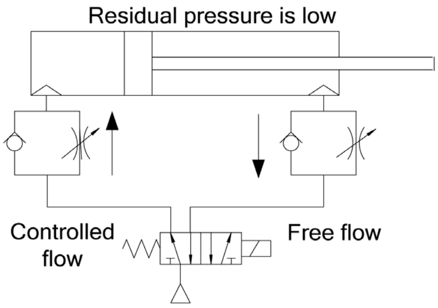


Figure 1. Meter-in circuit.

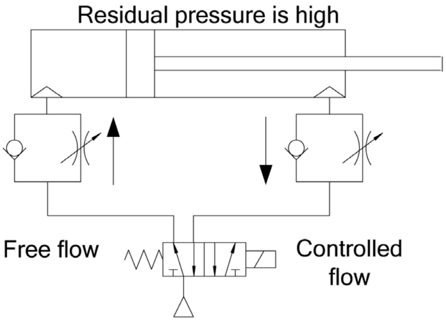


Figure 2. Meter-out circuit.

In addition, two merits of the meter-out circuit are described below.

One is the initial acceleration is very small because of the backpressure in discharge side, so that the piston will not move quickly. Another one is the cushion in the end part of the cylinder could play an important role due to the constant value of the pressure in discharge side.

3. Equations of Pneumatic System

The circuit of pneumatic system is shown in **Figure 3**. Four basic equations are shown as follows.

3.1. State Equation

When we derivative the state equations of air ($PV = mR\theta$) in charge side and discharge side, the following equations are obtained. Here, P is pressure; u is velocity of flow; S is pressured area; θ is temperature. And V represents volume; R represents gas constant of air; G represents mass flow rate. The subscript c and d refer to the charge side and discharge side, respectively.

$$V_c \frac{\mathrm{d}P_c}{\mathrm{d}t} = -S_c P_c u + R\theta_c G_c + \frac{P_c V_c}{\theta_c}\frac{\mathrm{d}\theta_c}{\mathrm{d}t} \tag{1}$$

$$V_d \frac{\mathrm{d}P_d}{\mathrm{d}t} = S_d P_d u + R\theta_d G_d + \frac{P_d V_d}{\theta_d}\frac{\mathrm{d}\theta_d}{\mathrm{d}t} \tag{2}$$

3.2. Energy Equation

Assuming that the value of heat transfer coefficient is constant, from the conservation of energy and the state equations of air, we obtain the following equations:

$$\frac{C_v P_c V_c}{R\theta_c}\frac{\mathrm{d}\theta_c}{\mathrm{d}t} = C_v G_u\left(\theta_a - \theta_c\right) + R\theta_a G_c - S_c P_c u + h_c S_{hc}\left(\theta_a - \theta_c\right) \tag{3}$$

$$\frac{C_v P_d V_d}{R\theta_d}\frac{\mathrm{d}\theta_d}{\mathrm{d}t} = R\theta_d G_d + S_d P_d u + h_d S_{hd}\left(\theta_a - \theta_d\right) \tag{4}$$

where C_v represents the specific heat at constant volume, h represents the heat transfer coefficient and S_h is the heat transfer area.

3.3. Motion Equation

The friction of piston is given by

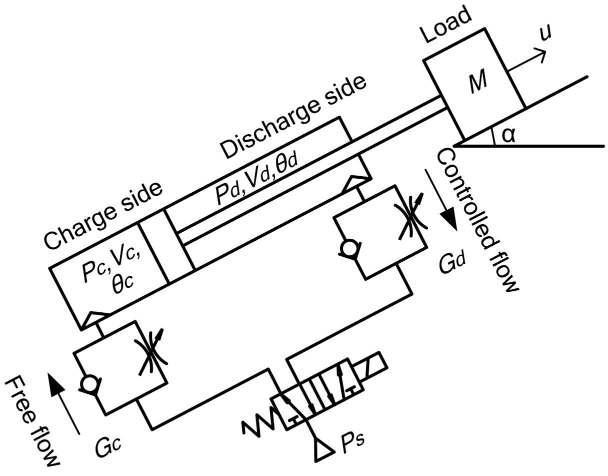


Figure 3. Meter-out circuit when driving a load.

$$F_f = \begin{cases} F_s & u = 0 \\ F_c + Cu & u \neq 0 \end{cases} \tag{5}$$

So the motion equation of the piston is

$$M\frac{\mathrm{d}u}{\mathrm{d}t} = S_c P_c - S_d P_d - P_a\left(S_c - S_d\right) - F_f - Mg\sin\alpha \tag{6}$$

The atmosphere pressure is represented by P_a.

3.4. Flow Equation

The air mass flow for the charge and discharge side of the cylinder are expressed as

$$G_c = C_c P_s \rho_0 \sqrt{\frac{\theta_0}{\theta_a}}\phi\left(P_s, P_c\right) \tag{7}$$

$$G_d = -C_d P_d \rho_0 \sqrt{\frac{\theta_0}{\theta_d}}\phi\left(P_d, P_a\right) \tag{8}$$

where the function ϕ is defined as

$$\phi = \begin{cases} 1 & P_2/P_1 \le b \\ \sqrt{1 - \left(\dfrac{P_2/P_1 - b}{1 - b}\right)^2} & P_2/P_1 > b \end{cases} \tag{9}$$

C is called as sonic conductance and b represents the critical pressure ratio. Where ρ_o refers to the air density and θ_0 refers to the air temperature (ANR).

Using the equations above, we can calculate the pressure and temperature change in the cylinder chamber, also the displacement and velocity of piston.

3.5. Energy Consumption

As shown in **Figure 4**, we consider a pneumatic cylinder system which is driven in vertical with a load. When the load is lifted by piston, the cylinder chamber is full of the charging air. Assuming that the state change of air in cylinder is an isothermal change, the following equation is used to calculate the approximation of the energy consumption E [5] [6].

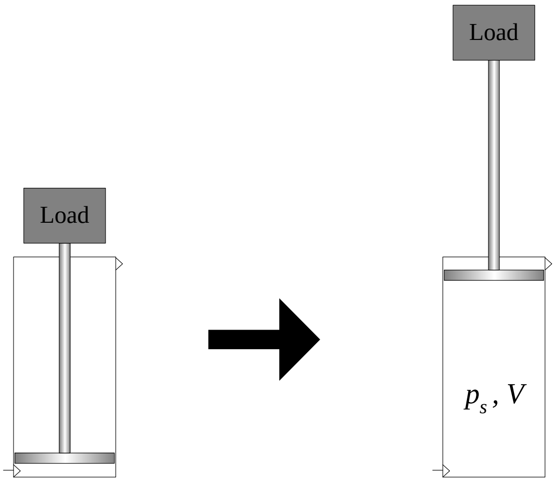


Figure 4. Energy consumption of cylinder.

$$E = P_s V \ln\left(\frac{P_s}{p_a}\right) \tag{10}$$

From this equation, we can clarify that the energy consumption in this condition is only relevant to the supply pressure.

4. Evaluation Experiment of Meter-Out Circuit

Experimental apparatus is shown in **Figure 5**. A cylinder (MBF 40-200, SMC Co., Ltd.) of inner diameter 40 mm and stroke 200 mm was set up vertically and driven upwards. A load of mass 5 kg/16kg was set in the front head of the piston. And there is an orifice of diameter 0.4 mm at the discharge side of the cylinder.

A solenoid valve was used to control the air flow direction and a regulator was used to keep supply pressure constant and to vary the initial pressure. In order to measure the energy consumption of cylinder, we used air power meter (APM) which could measure the transient flow rate and air power at the charging side.

Before the experiment began, the charge chamber was set up to atmosphere pressure and discharge chamber was set up to supply pressure. Then, we opened the solenoid valve and began the experiment in different supply pressure.

At first, the result of the *PQ* characteristics of orifice is shown in **Figure 6**. Here, the value of *C* and *b* are approximately 0.04 dm^3/(s·bar) and 0.5, respectively.

Secondly, the relationship between supply pressure and equilibrium velocity is shown in **Figure 7**. It can be seen that the equilibrium velocity become quickly with the increase of supply pressure. And then the velocity reaches to a constant value when supply pressure is higher than 350 kPa (abs). This is an important characteristic of meter-out circuit because of the velocity of air is chocked.

Furthermore, the relationship between supply pressure and energy consumption is shown in **Figure 8**. As stated above, energy consumption is only relevant to the supply pressure when the load is driven by cylinder. It

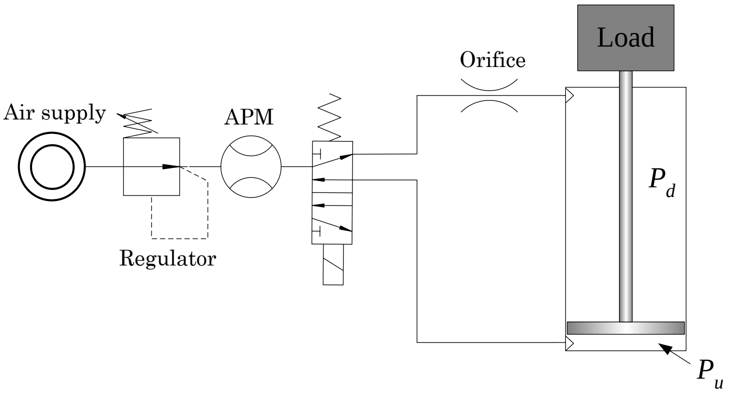


Figure 5. Meter-out circuit.

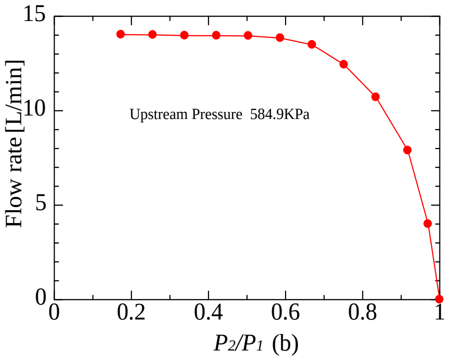


Figure 6. PQ characteristics of orifice.

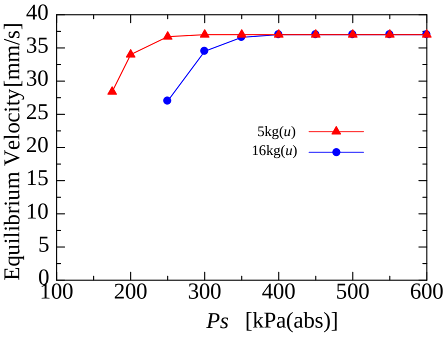


Figure 7. Relationship between supply pressure and equilibrium velocity.

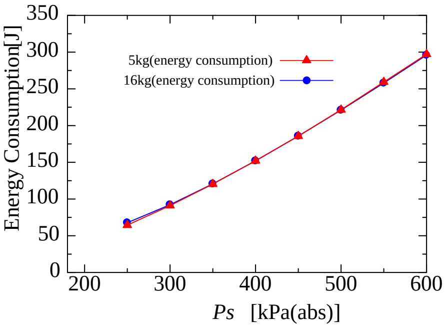


Figure 8. Relationship between supply pressure and energy consumption.

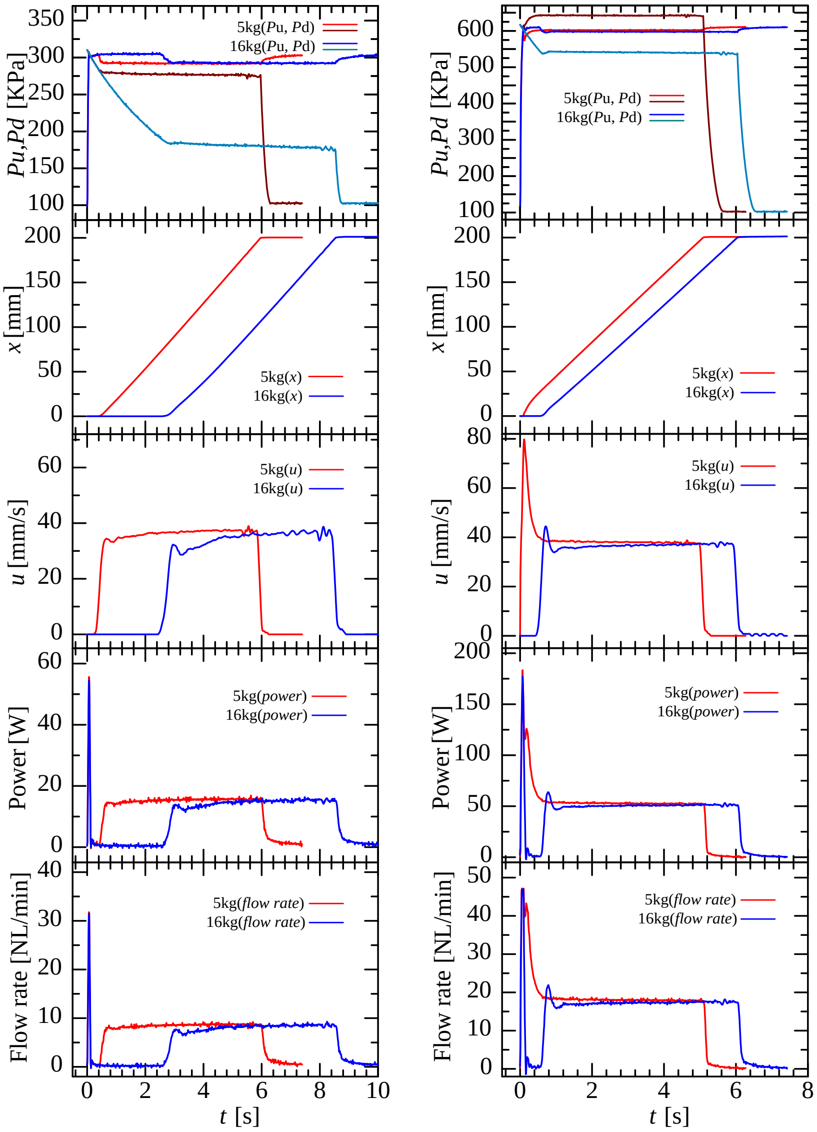
can be seen that the two curves of results in different condition are almost the same. It can be inferred that the energy consumption is increasing along with the supply pressure increased. In addition, we show the other experimental results in **Figure 9** as a reference.

The result showed that when the supply pressure is set up to 600 kPa (abs), the experimental result of energy consumption becomes 300 J during 6 seconds. On the other hand, from Equation (10) we obtained the theoretical result of energy consumption is 176 J. That means, approximately 40% of energy is lost without being used in this experiment. We considered that the reasons are orifice, piston friction and acceleration.

Furthermore, when the supply pressure is set up to 300 kPa (abs), the red line shows the power is approximately 15 W. Then we used velocity of flow and flow rate to calculate the power used in the process of charging is $W = PQ = 13.23$ W. Here, the velocity of flow is 35 mm/s. That means, over 80% of power is used for the control of velocity in meter-out circuit.

5. Evaluation Experiment of Meter-In Circuit

Experimental apparatus of meter-in circuit is shown in **Figure 10**. In this experiment, orifice was set up to the charge side. We use the same state equations and expression of energy consumption as in the meter-out circuit experiment. Experimental results in different conditions are shown in **Figure 11**. If supply pressure is low, the motion of piston reaches to an equilibrium velocity when the load is lifted. However, if supply pressure is too high, piston will move quickly due to the high-speed. We could not confirm that whether the motion of piston has reached to an equilibrium velocity or not. So we use the reaching time here instead of the velocity, and the relationship between reaching time and supply pressure is shown in **Figure 12**. It can be seen that the higher the supply pressure is, the shorter the reaching time is. In addition, **Figure 13** shows the relationship between supply pressure and energy consumption, the trends of curves are the same as the results of meter-out circuit. We can use the expression (10) to calculate the approximation of the energy consumption E. Here, according to the same supply pressure and equation, we obtained the same theoretical result of energy consumption is 176 J. The experimental result of energy consumption is 260 J. That means, the ratio of the energy loss is approximately 32%.



(a) (b)

Figure 9. Experimental results of meter-out circuit. (a) P_s = 300 kPa (abs); (b) P_s = 600 kPa (abs).

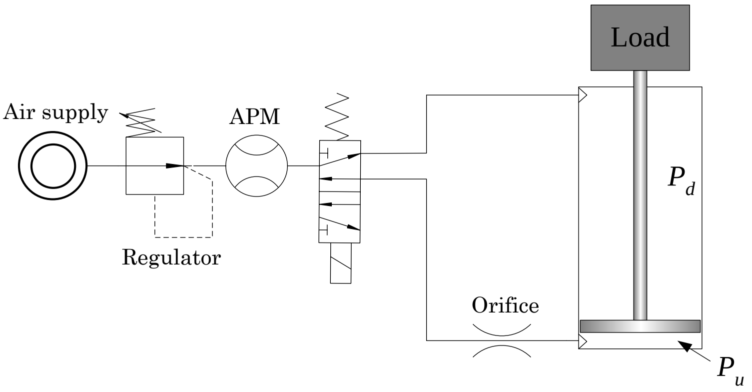
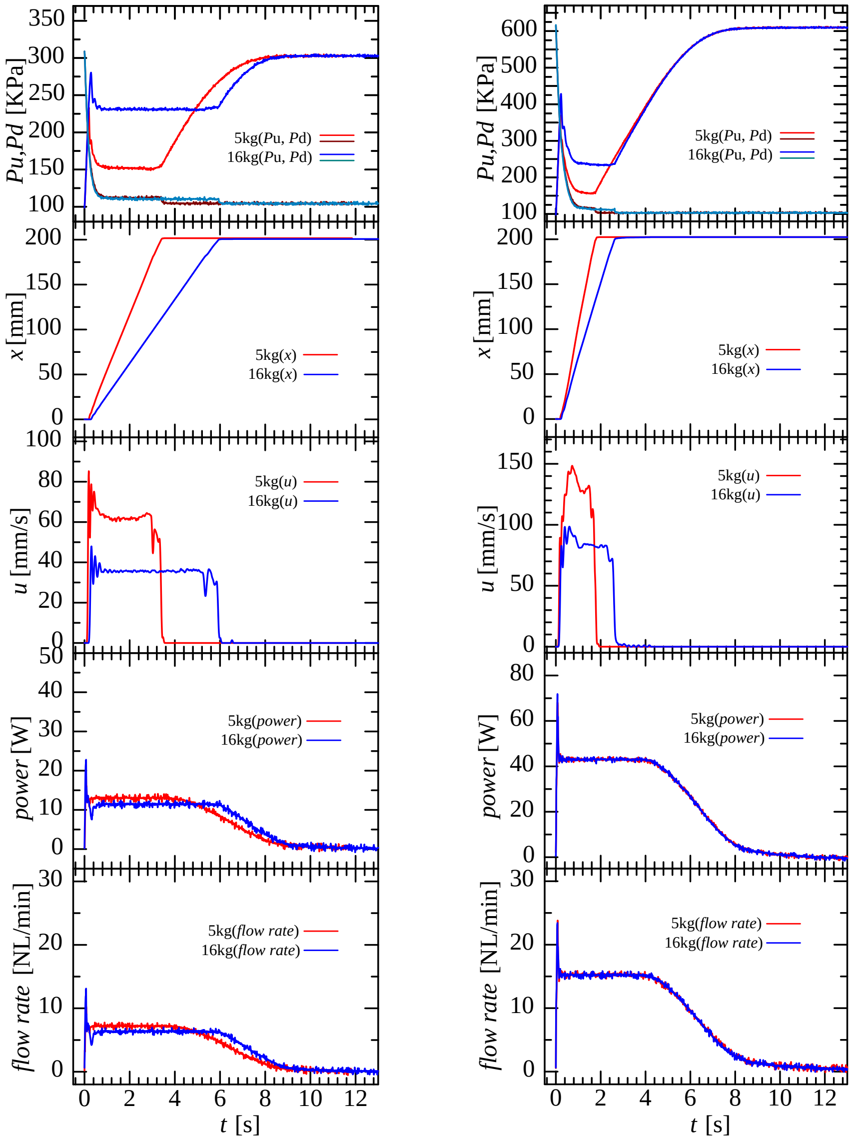


Figure 10. Meter-in circuit.



(a)

(b)

Figure 11. Experimental results of meter-in circuit. (a) P_s = 300 kPa (abs); (b) P_s = 600 kPa (abs).

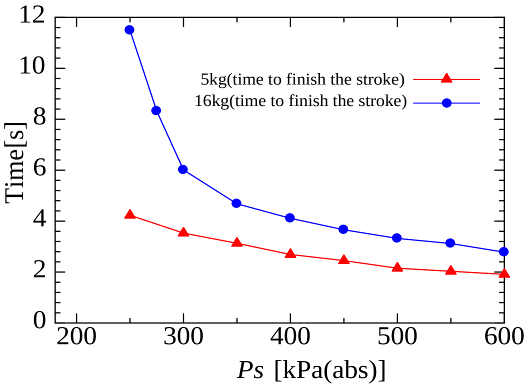


Figure 12. Relationship between supply pressure and reaching time.

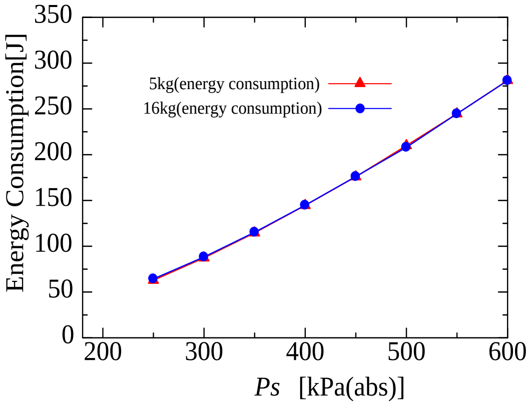


Figure 13. Relationship between supply pressure and energy consumption.

6. Conclusions

This paper showed experimental results of air transmission and energy consumption in pneumatic cylinder system by using air power meter. Experimental results showed:

1) Energy consumption is not relevant to the mass of load. It is mostly relevant to the supply air pressure.

2) The energy consumption in meter-out circuit is almost the same as in meter-in circuit.

3) There is approximately 30% - 40% energy loss occurs in this experiment. It is considered that the reasons are orifice, piston friction and acceleration.

4) In meter-out circuit, over 80% of power is used for the control of velocity.

With the assessment of energy consumption established, the quantification of energy transmission in pneumatic cylinder system will be realized. It is expected to be useful for energy saving research.

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Scientific Research

The Future Role of the Nuclear Energy in Brazil in a Transition Energy Scenario

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Abstract

This paper discusses and presents figures about the future power consumption in the world and, especially in Brazil, based on the current world and Brazilian's energy scenarios. Emphasis is given to the scenarios of nuclear power and uranium resources demand. A discussion on the future roles of thorium and uranium fuels in the replacement of the traditional resources like oil and gas is also presented, as it is the role of the new nuclear power plants, planned to be built in a short term time horizon. This paper considers two different indexes for future projections, and the results obtained indicated a strong dependence on them. The time horizon for the analysis was fixed on the time estimated for Brazil to reach its maximum in population, and parameters evaluated were taken from the Brazilian's governmental and world data on the population growth, energy consumption and energy consumption per capita. Calculations show that the power consumption projections for Brazil, for the adopted time horizon and working with global indexes, become overestimated, when compared with the results considering the national indexes. According to our approach, power consumption estimates using global indexes becomes approximately 4.5 times higher than the estimates presented by the Brazilian indexes. This was the motivation to the discussion between the Brazilian and world energy demand scenarios, and also the roles of nuclear energy in the future transition from the current conventional to alternative sources.

Keywords

Nuclear Energy, Renewables, Future Energetic Resources, Uranium, Projections

1. Introduction

The shortage of the most common used energy resources, such as oil, coal and water, and their growing consumption, together with the population growth and global warming, are phenomena clearly affecting the planet. The recent formation of tornadoes in the coast of Santa Catarina, which never happened or had been reported in

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all Brazilian history, the excessive melting of the polar ice caps, for example, can be foreshadows of a large scale global manifestations of uncontrolled and unpredictable climate changes, due to the exaggeration of the consumption of natural resources. Also, the increasing gap between economical and social classes and the pressure it exerts in the production of more expensive products, which also generates an enhancement in the energy consumption, clearly become an important issue on the countries future energetic planning. Besides the social and economical needs, planning must take into consideration the structure of the national energy matrix, and has to be based on what it can provide to support the country's growing perspectives. In this scenario, studies concerning the use and improvement in the technologies related to renewable or clean energies are growing and nuclear energy, among them, plays an important role.

Energy from renewable and nuclear resources, are considered candidates to reduce an incoming world energy crisis. Nuclear energy is one of the most promising candidates, despite the recent accident in Fukushima, since the technology is well developed and has a strong knowledge basis. Some countries are declining to build new nuclear plants. Nonetheless, it is interesting to note, for example, the acceleration of the construction of more secure power plants and the adequacy of the older ones to the new and more stringent security criteria in the world and in particular in United States. It shows a pressure in the production of energy, at least for this country. This can be an image of what might occur in the world in terms of energy consumption, but in a lesser scale, since United States, together which China, are the countries exerting the highest pressure in the consumption of the global energy resources [1] making their demands for energy more urgent. An argument which favors the utilization of nuclear energy is given, for example, in the work of Haratyk and Forsberg [2]. They devised a coupling between nuclear energy and renewable facilities. According to them, renewables cannot supply the increasing demand of energy in the short term, given the current countries technological status.

Thus, it is expected that nuclear energy will replace in a large scale and in a short term, the conventional resources, increasing its participation in international and national scenarios of energy demand. But it cannot be accomplished without a deep study about the future supply of nuclear fuels, mainly uranium and, for a more advanced perspective, thorium.

Both minerals are abundant in Brazil, and for the national projections, uranium is available in sufficient amounts to supply the four planned PWR reactors, to be constructed up to 2050 [3]. Even having the technology knowledge of all the fuel cycle, the energy matrix in Brazil is mainly hydroelectric and nuclear represents 3%. In the world, nuclear energy is about 17% of the total generated electricity, and about 5.4% of the total world energy consumption. However, in a transition energy scenario, even with the recent discoveries of oil reserves in pre-salt formations in the Brazilian coast, having a potential to increase power in our energy matrix, with the construction of the Belo Monte hydroelectric power facility, abundance of solar radiation over the entire year covering all our territory, etc., nuclear power could be a short term solution of a possible energy supply delay, expected for the years to come, up to the development of the renewables technology to reach efficiency levels, suitable for commercial exploration. Besides, the development of the technology of the extraction and purification of the small amounts of uranium from the recent discovered phosphatic deposits [4], which covers almost one third in area of the Brazilian territory, will improve the reserves and also the capabilities of the expansion of its nuclear and, thus, energetic matrix.

The construction of nuclear power facilities is also a matter of public discussions, mainly concerned about the safety requirements and accident risks, which rises again after the recent Fukushima's accident. From the arguments above and the discussions to be presented in the next items, it is easy to see and, according to our opinion, that Brazil has a privileged position in terms of the availability of energy resources, including uranium. This privileged position could be used to overcome public rejection and to support the acceptance, even in the long term, to the Brazilian's initiative in the direction of the construction of new nuclear power facilities in Brazil, since massive investments in nuclear power, like those in United States and China, are not planned [3]. However, for a long term planning, energy consumption estimates must be calculated on reliable basis, emphasizing both the global and national scenarios in the current energy context.

This paper analyzes and estimates the future power consumption in the world and in Brazil, based on the current worlds and Brazilian's energy scenarios, with emphasis to the scenarios of nuclear power and uranium resources demand. A discussion about the future roles of thorium and uranium fuels in the replacement of the traditional resources like oil and gas, the advantages of thorium in terms of energetic efficiency, is also presented. As a consequence of the uses and availability of the nuclear fuels, the role of the new nuclear power plants, planned to be built in a short term time horizon, is also discussed in this same scenario. Emphasis was given to the called 2DS scenario [5], which means a scenario where it is predicted a minimum of 2˚C for the increasing in the global mean temperature, up to 2025. Actions and plans are under discussion, each one of the possible new technologies having specific advantages and drawbacks [5].

The comparison presented in this paper pointed out a strong dependence on the two different indexes, used for future projections. Global indexes were extracted from the projections made in the Tomabechi's work [6] for the world consumption, which deals with the relation between energy consumption indexes and world's population growth as the parameter to be evaluated. These results were extended to make projections for the Brazilian case. Brazilian indexes were based on the national projections for the population growth, listed by IBGE [7] and were used for the future projections. To check for the importance of domestic scenarios in the projections, graphics are given to show the evolution and to compare global and domestic parameters such as population growth, power consumption per capita and total power consumption in some countries.

The time horizon for the analysis was fixed on the time estimated for Brazil to reach its maximum population, and parameters evaluated were taken from the Brazilian's governmental and world data on the population growth, energy consumption and energy consumption per capita.

This was the motivation to both discussions carried out here, one associating Brazil within a global transition scenario, and the other which dissociates our country from the global considerations, discussing our future projection results in a domestic perspective. Since nuclear is the prompt alternative instead of the undeveloped renewables technology, it is also discussed its role as the main alternative to the replacement of the current conventional ones.

2. Nuclear Energy in a Transition Energy Scenario

Concerning today's debates regarding energy demand and global warming, a transition energy scenario, according to reference [5], means that world needs to change from the prevalent high-carbon/high-pollutant technologies to the incoming low-carbon/low pollutant ones, from the exploitation of the energy resources through the generation of energy. However, considering the phenomena of the development of those new technologies as a dynamical process, demanding time and consuming resources (energetic and monetary), it is known that it usually does not evolves with time at the same rate as that necessary to overcome the problems for the today's climate changes and energy consumption.

Since earth is a dynamical system, it is continuously changing, through changes in its observable properties with time. However, since the time human beings are exploring its resources, they become one of the major causes of changes on earth's properties, the most sensitive of them and most easily visualized and studied are those related to weather. The problem is, at the today's rates of consumption, these changes are possibly leading humanity to an irreversible path and, the worst of all, in a short period of time. Technology and human intelligence solved several problems of our everyday life, enabling us to go to the moon, to explore planets, the universe and the subatomic world, to defeat diseases, communication problems, etc., but its side effects is presenting itself as a very harm one.

Based on the current status of the renewable technology development and the growth of the mean earth's temperature, scientists devised 3 possible states for the future global weather, based on 3 possible values for the increase in the mean earth's temperature. Based on that, governments can take action plans to deal with these three possible scenarios; changes in the energy policy are necessary to be planned, defined and studied to provide approaches for the solution of the incoming energy problems. The above scenarios go from the minimum to the maximum harm for the living beings in the planet. They are called XDS scenarios, where X = 2, 4 or 6 and stands for the expected increase in the mean earth's temperature, in degrees C, for a fixed time horizon of 2025.

It is pointed out by reference [5] that energy technologies like solar and photovoltaic are promising to reach the 2DS requirements, but the ones with greatest potential to reduce carbon emissions, like the nuclear, are making the slowest progress, since security is the main topic of interest for the public acceptance and for its full utilization. It is expected a growth of 600 GW of nuclear installed capacity to reach the 2DS requirements, but after the Fukushima's accident it is also expected a deployment in 100 GW, becoming this process a complicated one.

For the projections of the future of the energy supply by nuclear energy, the repercussion of the 2011 accident was fundamental, leading United States to review the current security criteria for the construction of the 22 planned new nuclear power plants, which are based on the intrinsically safe AP1000PWR design, mostly from 100 MW to 300 MW power. Despite of its safety aspects, however, some authors still criticize its design, like Piore [8], who emphasizes that the security factors for the pressure vessel's project is undersized. For the breeder reactors, another technology being considered which enables the extension of the fuel's lifetime, Cochran [9] emphasizes the problem of the isolation of sodium and water lines, critical due to the risk of explosions. Those are issues that testify against the use of such technologies.

However, according to the World Nuclear Association data [10], in addition to the today's 441 nuclear reactors in the world, more 338 nuclear reactors are planned to be constructed, four in Brazil [10]. Based on the same report [10], in 2011 83 reactors were under construction, most of them are PWR, according to **Table 1**.

On June 1st, 2010, Brazil restarts the construction of the Angra III nuclear power reactor and, together with the planned four, as stated recently in 2012. Our supply of nuclear power will increase in approximately 5300 MW. More ambitious construction plans are presented by China, Russia, United States and Ukraine which are planning to build, respectively, 115, 40, 30, 28 and 20 more nuclear power reactors, a total of 223, mostly based on the LWR technologies. Thus, despite the accident and the rising of the unfavorable public opinion against the construction of new nuclear power plants, it is observed [5] that most of the countries kept their nuclear programs active. But the only factor that has changed is the speed on which the new facilities are planned to be constructed.

Another favorable point for the installation of new nuclear plants was devised by WEC [11], also having as basis that this technology is well developed. In this document it was suggested that, to accelerate the transition from Green House Gas, GHG, to non-GHG technologies, nuclear expertise could be shared from the nuclear developed countries to the non-developed ones. According to WEC [11], this could be another way of global scale cooperation for the reduction of GHG emissions and to develop the 3rd world technological infrastructure, aiming the minimization of the time for an undeveloped country to reach an acceptable level of technology to deploy clean energy technologies. Also, [11] states that new rules for patent interchange and utilization must be redefined, for the humankind to adapt to the new survival requirements. Sharing costs could be viewed by the leading technological countries in the world as a logical path. Since global warming and energy consumption is a world problem, large-scale technology as well as costs should be diffused at same basis in order to share a solution in the direction of the reduction of the global costs of the pollution through the deployment, for example, of the clean energy technologies. This is an important point of debate in the more recent seminars on greenhouse gas emissions and the future of the climate of the planet

We have to keep in mind that important differences arise if the scenario for the estimates is taken locally. For example, countries with high number of nuclear reactors, large populations and with large energy consumption, like United States, China, European Union, etc., global indexes obviously do not reflect the truth about the national estimates for these countries, since they pull the mean world values of consumption/demand of electricity upwards. For example, in terms of the greenhouse gas emissions, it is observed that 50% of the total is due to oil and coal usage, mainly from United States and China. Thus, there is a mistake of sharing the indexes/costs. It is suggested here a criterion for the evaluation of a real "contribution" of a country for the global energy consumption.

For Brazil, the technology for clean energy deployment is still in a growing phase for some of the renewables, in terms of the domestic energy supply index. According to Cerri [12], 41% of Brazil's total domestic energy supply comes from renewable resources, against 14% as a mean value in the world and 6% in industrialized countries.

Table 1. Nuclear reactors under construction or "almost so", by design [10].

Reactor Design	Quantity
Fast Breeder Reactor	02
Pressurized Water Reactor	61 (China = 26)
Pressurized Heavy Water Reactor	11
Advanced Boiling Water Reactor	08
High Temperature Gas Reactor	01
Total	83

This outcome implies a reduced dependence for imports of energy sources, and an advantage in terms of energy supply for the future, even its nuclear park representing only 3% of the total energetic production. Thus, the use of local indexes could be a better choice, for a better accuracy for projections of energy consumption. But it is important to observe that Brazil holds the position to be one of the top green-house gas emitters in the world, mainly due to the deforestation to livestock and agricultural uses [12].

3. The Uranium Scenario

To see how uranium resources can provide a short term solution to face a possible energy supply crisis, it is convenient to compare the world's uranium reserves capabilities with those of oil and coal, the most used natural resources in the world.

For generating 375 GWe, the corresponding electricity generated by nuclear fissions, it is required 68,000 t of uranium per year. According to **Table 2** [13], and ignoring the so called secondary sources of uranium (uranium from nuclear weapons, reprocessing, etc.), if the total estimated amount of uranium metal is 5.5 Mt, at the above rate of consumption the uranium reserves will last 80.8 years. This amount is enough to reach the so called 2DS objectives up to 2025 [5], where the required power related to nuclear energy is about 600 GWe. The difference of 225 GW corresponds to 40,000 t of uranium per year, an enough amount to cover 2DS requirements. As explained below, the Fukushima accident changed some policies related to the construction and operation of new nuclear power plants, the value of 600 GWe must be reduced for this reason.

In terms of oil, based on the current consumption rate, 8.2×10^7 barrels/day, and considering it as constant, a non-realistic hypothesis, its length can be calculated in almost 41 years. United States is the planet's largest consumer of this resource, with approximately 1.9×10^7 barrels/day, nearly 25% of the world's consumption, and Brazil appears in seventh place, 2.5×10^6 barrels/day. Regarding coal, China is in the first place, with 1.31×10^9 tons/year, followed by the United States, with 1.06×10^9 tons/year, and together account for 50% of the world's total consumption, and also for the corresponding greenhouse gas emissions. Brazil appears in 19th

Table 2. Known recoverable resources of uranium (Reasonably Assured Resources plus Inferred Resources, to US$ 130/kg U, 1/1/09, from OECD NEA & IAEA [10]).

Country	Tons of uranium	% of world's total
Australia	1,673,000	31.0
Kazakhstan	651,000	12.0
Canada	485,000	9.0
Russian Federation	480,000	9.0
South Africa	295,000	5.5
Namibia	284,000	5.0
Brazil	279,000	5.0
Niger	272,000	5.0
United States	207,000	4.0
China	171,000	3.0
Jordan	112,000	2.0
Uzbekistan	111,000	2.0
Ukraine	105,000	2.0
India	80,000	1.5
Mongolia	49,000	1.0
Other countries	150,000	3.0
World total	5,404,000	100%

place, with 2.3×10^7 tons/year, twice orders of magnitude less than the previous two [14]. In terms of proved coal reserves, considering that there are around 522 billion tons, the current consumption rate of 4.59×10^9 tons/day [14], and supposing that rate remains constant for the following years, we can estimate that the reserves will last 113 years. In both cases, uranium can be seen as the readiest resource for their possible replacement. For example, as previously mentioned, primary resources of uranium will end, at the current consumption rate, in about 80 years, in the mean value, accounted for the world, not for a particular country figure.

For Brazil, with the estimated growth scenarios for our nuclear matrix [15], from the current 1.95 GW to 3.5 up to 7 GW, our reserves will last 120 to 240 years (reserves of uranium considered at a total cost of less than US$ 130/kg, the criteria for an economical exploration of an uranium mine) and from 200 to 400 years, taking into account also the inferred reserves. A safer estimate, which predicts a maximum percentage of the total electricity generated by the Brazilian nuclear matrix of 5.7%, excluding the estimated by INB [4] inferred reserves of 800,000 tons, the duration of our uranium resources is, in the worst scenario, about 90 years. Taking into account these reserves, together with the 279,000 ton of uranium metal, the estimates are for the operation of 10 nuclear reactors like Angra III, for 200 years [16]. The problem is that most of the uranium in the inferred reserves comes from phosphates, and the technique for uranium extraction from phosphates is still uneconomical. The same problem in terms of the costs/economy of extraction is presented with the uranium obtained from sea water, whose amount is estimated in 3.3 ppb [6].

Since most of the energy generated in Brazil is from hydropower, and since the water resources are now limited due to considerations of preservation and other environmental aspects [16], to cope with the hydropower restraint in terms of space, nuclear expansion in terms of the self-sustained scenario would be helpful, according to the data presented in **Table 3** presented in the next item.

Thorium is another source of fissionable isotope, U^{233}, its reserves are estimated to be 3 times higher than uranium's. In the work of Ashley [17], it was stated that the amount of thorium as a by-product of rare earth processing would be enough to feed 200 nuclear ADTR ("Advanced Thorium Reactor"), without the need to open new mines for exploration and extraction, thus with no initial investments. Also, other advantage of thorium compared to uranium is its total usage as nuclear fuel as extracted from the mines, instead of the 0.7% relating to the fissile isotope U^{235}, present in U^{238} matrix. It means, according to Ashley [17] that for each GW of electricity produced, only 1 ton of mined thorium is necessary, whereas 200 tons of uranium from the mines or 3.5 Mt of coal would be required to produce the same amount of electricity.

Although there are still doubts about the real need for the construction of new nuclear power plants in Brazil, the debate is still open, and the numbers shown in the tables and the scenarios presented above are favorable. Considering the capabilities of the Brazilian nuclear reserves, it will be described and simulated, in the next items, some possible scenarios for its utilization in relation to two parameters, among the huge numbers of variables that usually affect a more complete analysis, population growth and energy consumption.

The scenarios for the national analysis were taken from the Plano Nuclear Brasileiro 2030 ("Brazilian Nuclear Plan 2030") [18], from EPE and Eletronuclear. A comparison will be made with results found in recent literature.

4. Projections: Energy Consumption and Demand, and Population Growth

Since population and the energy consumption growths are some of the most significant parameters to pressure energy demand, the projections for the Brazilian population growth, presented by the data of IBGE [7] in **Figure 1**, are firstly analyzed before the estimates of energy needs. Other sources for population growth projections are available, like the CIA fact book [1]. According to IBGE, the maximum in Brazilian population will occur in

Table 3. Electricity consumption generated via nuclear power, for inhabitant year, according to the scenarios of the PNB 2030 and using Equation (2).

Scenarios of growth	Year 2030 [MJ/(inhab. year)]	Year 2040 [MJ/(inhab. year)]
Minimum (2.7%)	190.89	200.34
Development (4.2%)	296.94	311.64
Self-sustainable (5.7%)	402.99	422.94

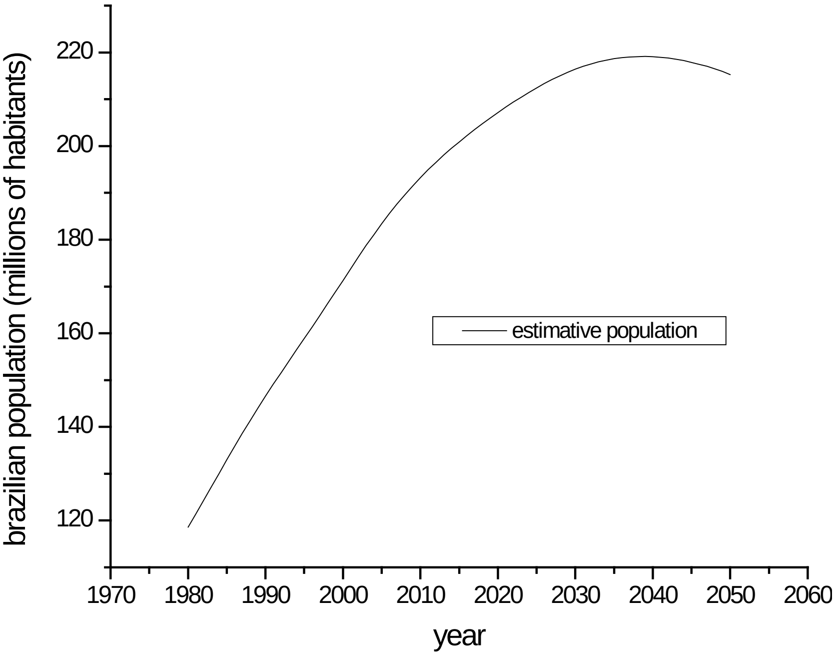

Figure 1. Brazilian population projection, up to 2050 [7].

2039 (219,124,700 inhabitants). However, between 2020 and 2030, the limits of the proposed energetic planning horizons [3] [19], our population will have approximately 212 million inhabitants.

The parameter energy consumption growth, would give accurate predictions if analyzed for each country, instead of taking the estimates based on global indexes. To put both parameters together, we observe that Iceland has the highest index of energy consumption per capita in the world, but its population is below 5 million people, meaning its contribution to the total world energy consumption is low. Countries with the highest energy consumption per capita are China, the United States, Japan, Russia, India, Canada, South Korea, South Africa, Australia, and the European Union. Taking together population growth and absolute population, these countries are not the first ranked ones (in terms of growth rate, East Timor, with 4.5% by year, is in the first place [1]), but pressure the energy consumption by their high number of inhabitants and also by their high energy consumption per capita. The Brazilian energy consumption per capita can be seen in **Figure 2**. The consumption per capita for the most populated countries is given in **Figure 3**, to acquaint for the differences mentioned in the introduction.

In terms of world energy consumption, it is important to observe that countries of the Europe and North America have lower population growth rates, but their energy consumption is about 1 order of magnitude higher than the mean world energy consumption. This is shown in **Figure 4** and **Figure 5**.

In a recent paper from Tomabechi [6], it was estimated that when the world population reaches $\mathbf{N_{hm}}$ = 10 billion inhabitants, around the next 30 to 50 years, according to the current global mean population growth of 81 million people/year, the energy demand will be $\mathbf{C_m}$ = 2 ZJ/year (where 1 Z = 10^{21}). This number was defined, according to the authors, based on data about the energy resource consumption of developed countries, extended to all the countries of the world. Thus, the estimated energy world consumption per inhabitant ("per capita"), $\mathbf{C_{pc}}$, at the time of $\mathbf{N_{hm}}$, would be:

$$\mathbf{C_{pc}} = \mathbf{C_m}/\mathbf{N_{hm}} = \left[2\times10^{21}\,(\mathrm{ZJ/year})/10^{10}\,(\mathrm{inhabitants})\right] = \mathbf{200\ \ BJ/(inhabitant\cdot year)} \qquad (1)$$

where BJ = 10^9 J = billion Joules, for a hypothetical scenario which predicts equality in the future energy consumption pattern for all the world's population. It is shown in the following graphs that the developed countries are in general the largest energy consumers, and having the highest energy per capita consumption rates, just to confirm that global indexes do not represent local realities.

According to the indexes presented by Tomabechi [6], to start the projections of $\mathbf{N_{hm}}$, since nuclear power accounts for approximately 5.4% of the total energy consumption in the world [1], the demand for this resource would be:

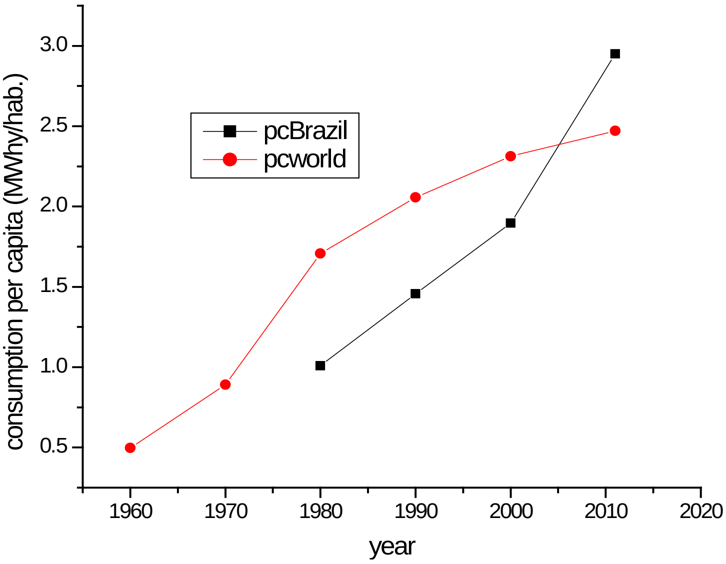

Figure 2. Consumption per capita, Brazil.

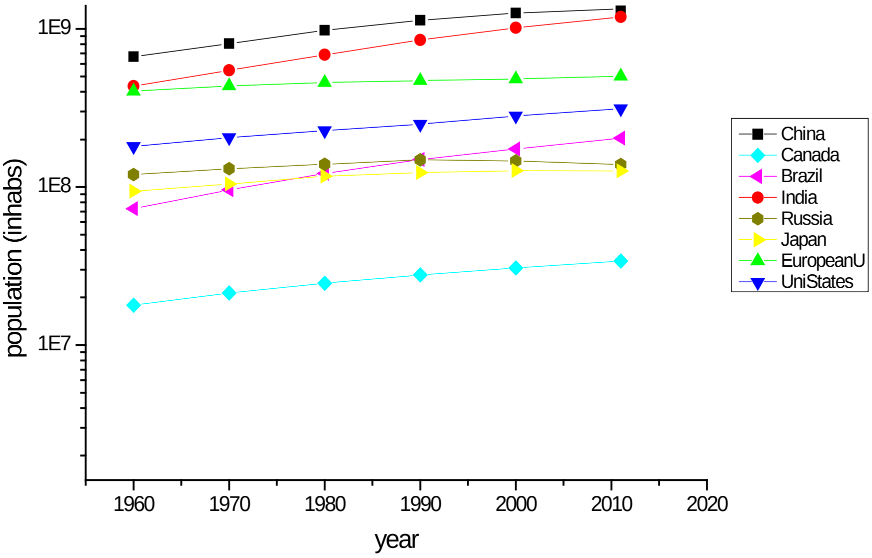

Figure 3. Population growth of the most populated countries.

$$\mathbf{C}_{\mathbf{pcnuke}} = 10.8\ \text{BJ}/(\text{inhabitant year}) \tag{1′}$$

From the IBGE data [7], in 25 years, the Brazilian population $\mathbf{N}_{\mathbf{hBr}}$ will reach its maximum at 219 M inhabitants (**Figure 1**, where 1M = 10^6), at about the same time the world population is estimated to reach $\mathbf{N}_{\mathbf{hm}}$. It can be predicted that, taking into account the above hypothesis, the Brazilian energy consumption per year, $\mathbf{C}_{\mathbf{Br}}$, will be:

$$\text{C}_{\text{Br}} = \text{Cpc} \cdot \text{N}_{\text{hBr}} = 200 \times 10^9 \, (\text{J}/\text{inhabitant year}) \times 219 \times 10^6 \, (\text{inhabitant}) = \mathbf{0.0438\ \ ZJ/year} \tag{2}$$

corresponding to 2.19% of the global energy needs.

From an estimate based on the data of the 2005 Brazilian National Energy Balance presented in [15], assuming a constant growth rate of 0.67% per year in relation to the total energy consumption, and 0.64% relating to the electricity consumption, some estimates can be carried for the total energy consumption per inhabitant in Brazil, $\mathbf{C}_{\mathbf{pcBrtotal}}$.

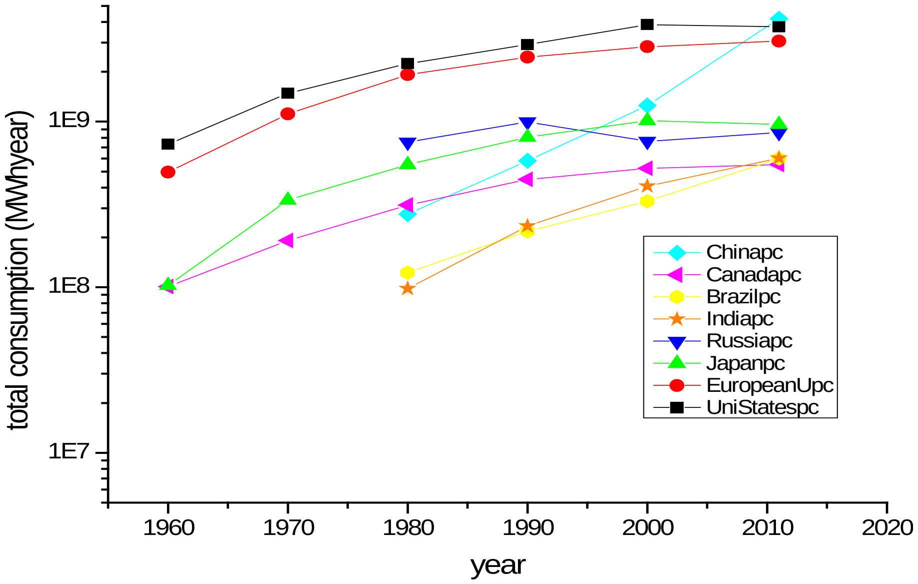

Figure 4. For the same countries of **Figure 3**, total energy consumption.

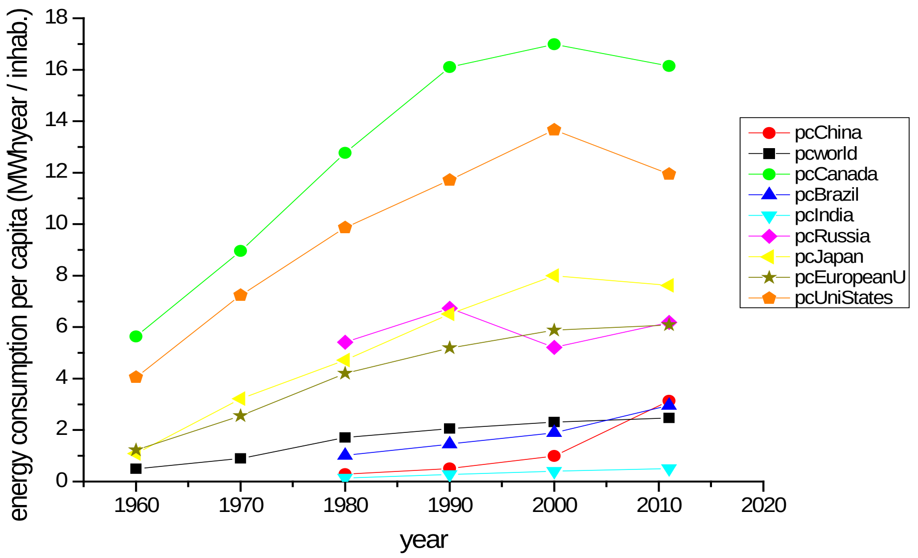

Figure 5. For the same countries, energy consumption per capita.

First, for the total energy consumption, the result is, for 2030:

$$\mathbf{C}_{\mathbf{pcBrtotal}} = \left[9.518\times10^{-3}\left(\mathrm{ZJ}/\mathrm{year}\right)/216,010,430\left(\mathrm{inhabitants}\right)\right] = 44.1\ \mathrm{BJ}/\left(\mathrm{inhabitant\ year}\right) \qquad (3)$$

and for 2039:

$$\mathbf{C}_{\mathbf{pcBrtotal}} = \left[1.0175\times10^{-2}\left(\mathrm{ZJ}/\mathrm{year}\right)/219,124,700\left(\mathrm{inhabitants}\right)\right] = 46.4\ \mathrm{BJ}/\left(\mathrm{inhabitant\ year}\right) \qquad (4)$$

both results nearly 4.5 times lower than the value of C_{pc}, predicted according to Tomabechi methodology [6], and to the relation in Equation (2). This result shows that the differences can be very high if the estimates are taken from global indexes, which are average values, justifying the use of domestic indexes for the estimates. The goal is not to criticize or favor any methodology, but just to point out that there is a need to present them comparatively, if working together on the reduction or sharing pollution/clean energies deployment costs.

Taking into account a Brazilian scenario provided by EPE/Eletronuclear [15] about the future participation of the nuclear power in the energy matrix in Brazil, and the INB [4] projections for the Brazilian uranium supplies, its future contribution to the energy demand can be estimated, and the results compared to those from Equation (2).

According to the scenario devised in the EPE document [15], nuclear energy participation in the national electricity demand would grow from the current 2.5% (from a current national total of 78 GW) to 2.7%. Thus, it will be necessary one more nuclear power plant with capacity of 100 to 300 MW and the nuclear matrix will grow from 1950 MW to a maximum of 3550 MW, considering also the construction of Angra III. This work also stated that, in a so called simple development scenario, the estimated participation of nuclear would be 4.2%, comprising the construction of one more nuclear power plant 1300 MW power, (together with Angra III) and two other nuclear power plants of 300 MW each, adding 3200 MW to the current 1950 MW, and making up a total of 5150 MW. Finally, in a so called self-sustained development scenario, more interesting to the safe future supply of energy for the next generations, an increase of 5.7% would be supported by the construction of two new nuclear power plants 1300 MW power each (together with Angra III), and four more new modular stations 300 MW power each. The electricity generation capacity via nuclear power would grow from the current 1950 MW to 6950 MW.

Thus, the participation in the energy consumption in Brazil per inhabitant in relation to nuclear energy can be estimated according to those three scenarios, and the results are shown in **Table 3**, where MJ is equivalent to millions of joules.

Using the assumptions described above for the consumption rates for the total energy and for the energy from electricity, and the values obtained by the relations (3) and (4), we can obtain the electricity consumption values projected for 2030 (16.04%) and 2039 (15.88%). Thus, for 2030, the result of the Brazilian projected electricity consumption demand, $\mathbf{C}_{\mathbf{pcBrel}}$ would be:

$$\mathbf{C}_{\mathbf{pcBrel}} = \left[9.518\times10^{-3}\left(\mathrm{ZJ/year}\right)/216,010,430\left(\mathrm{inhabitants}\right)\right]\times0.164 = 7.07\left(\mathrm{BJ/inhabitant\ year}\right) \tag{5}$$

and for 2039:

$$\mathbf{C}_{\mathbf{pcBrel}} = \left[1.0175\times10^{-2}\left(\mathrm{ZJ/year}\right)/219,124,700\left(\mathrm{inhabitants}\right)\right]\times0.158 = 7.37\left(\mathrm{BJ/inhabitant\ year}\right) \tag{6}$$

Considering the self-sustained scenario, electricity generation via nuclear power in the years of 2030 and 2039 in Brazil would be approximately 9×10^{-5} ZJ/year, corresponding to 7.1 GW of projected power.

5. Conclusions

Taking the current indexes for the world electricity consumption into consideration, pushed up mainly by the developed and highly industrialized countries, and assuming that they are the same for the developing countries, by the time world's population reaches 10^{10} inhabitants, calculations show that the power consumption projections for Brazil, for the adopted time horizon and when using global indexes, become overestimated, when compared with the results calculated by our national indexes. According to our studies, power consumption estimates using global indexes becomes approximately 4.5 times higher than the estimates based on national indexes. Global indexes, as taken by several works and particularly the work of Tomabechi [6] analyzed here, are not reflecting the national realities in terms of energy consumption and demand, as is the case of Brazil.

Data here used for the predictions are subjected to changes and to the accuracy of the governmental agencies at the time of their publication. In the Brazilian case, the recent discovered pre-salt oil deposits offer a possibility for a different solution to a possible energy crisis, when compared, for example, to the United States. Together with China and the European Union, they are responsible for almost 65% of the world's energy consumption, having also combined factors like large population and large energy consumption per capita. Both factors lead to high levels of emissions and to the fast depletion of the current natural resources.

However, despite the great potential of the Brazilian reserves of uranium, water, oil, etc., clean energies must also be taken into consideration in the future, to meet the 2DS requirements. For a non-GHG-emission source, nuclear is the most available candidate. For Brazil, together with the renewables, the nuclear option could be a quick start to solve the problem of emissions due to deforestation, our main source of greenhouse gases.

Construction of nuclear power plants is always a subject for debates and speculation, impacting the forecasts of consumptions of uranium and thorium, by means of a correct campaign for the public acceptance. It was stated above that a way to reach some equilibrium condition could be achieved, however, if countries agree to diffuse their energy technologies for other countries, developing or under-developed, since they are at most low carbon emitters and usually still don't have enough technology development to carry out projects on clean energies. Sharing the technologies could be a fast contribution for the solution to the growing problem of climate changes.

Relating to nuclear energy, at least four factors, mentioned is this work, can put Brazil in a comfortable position in front of a possible crisis in the future demand for energy: 1) uranium: since we have enough uranium in the Brazilian territory, and counting with the future improvement of the process of uranium extraction from phosphates; 2) thorium: since Brazil has also enough reserves, for future uses in new technology nuclear power reactors; 3) population growth stability: according to the governmental projections; and 4) nuclear fuel cycle know-how.

Climate instabilities can reach us all in a near future, and global warming is one of its possible triggers. Besides, human activities play a very important role in the contribution to the instability of the weather in a global scale. The increase in the demand for energy, in the population growth, mainly in the last 50 years, leading to the increase of the greenhouse gas emissions and to all the climate instabilities we have been facing, should be assessed considering the appropriate indexes. Thus, according to this work, a different criterion must be stated, for the world to face this problem fairly, since a huge amount of investments will be needed to control or to reduce the threat of the so called "non-turning point" phenomena, in terms of the global weather.

Thus, the future transition between the massive global uses of fossil fuels to a massive global use of the alternative sources, supported by our nuclear know-how, could be carried out in such a way to help us in the improvement of the life quality in our country, and as a consequence, in our planet.

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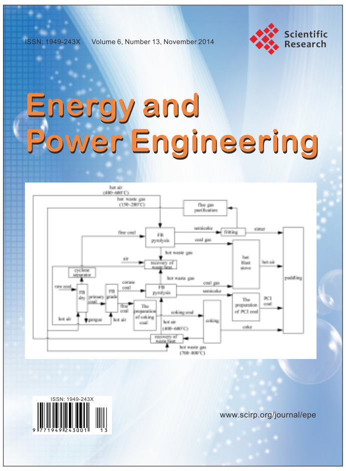

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