Proceedings of the Seventh IASTED International Conference
POWER AND ENERGY SYSTEMS
November 28 - December 1, 2004, Clearwater Beach, FL, USA

Research on Superclean Polygeneration Energy System of Iron and Steel Industry

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Abstract

In this paper, based on gas polygeneration, an innovative idea is proposed in iron and steel industry to improve energy efficiency and reduce pollutant emission. In order to solve the problems existing in COREX smelting reduction casting technology, here puts forward coal-gas byproduct polygeneration strategy of COREX. In addition, making full use of potential advantages of special gasifiers such as converter, blast furnace and coke ovens, a new development idea of coal-gas polygeneration in iron and steel enterprises are proposed. It makes a breakthrough compared with conventional theory of Energy Conservation and Loss Reduction. Last but not the least, the concept model of future super clean iron and steel polygeneration system is established here, as a result, the sectors of the future are not only high-quality, low-cost iron and steel producers, but also the real clean and green energy systems.

Key words:

energy policies, power system planning, power generation, polygeneration strategy

1. Introduction

Coal is and still will be the dominant primary energy in China due to its properties of energy resources. The development and utilization of coal causes increasingly severe environment problems. Iron and steel is one typical industry mainly depending on coal, and in China, its energy consumption accounts for about 10% and the dust emission is about 1.1 million tons, accounting for more than 13% of the total.[1]

The iron and steel industry of China grows robustly for years and the yield of steel hit the score of 200 million tons. However, the trend of blind investment and low-level expansion is prevalent, and this low-level investment further intensifies the structural contradiction and results in serious resource waste and environment pollution.

According to existing glowing mode, the development of iron and steel industry in China is somewhat unsustainable.

2. Idea of polygeneration energy system

The idea of integrated energy/resource/environment polygeneration energy system is on the basis of coal gasification, and it is necessary for the future sustainable energy development of China. More important, it supplies an innovative development mode for iron and steel industry[2].

Among the coal consumption mix, electricity generation, metallurgy, chemical and building materials industries occupy most part. Polygeneration shows the way to eliminate pollution problems instead of dividing sectors artificially, that is, polygeneration integrates the resource, emission, energy and process information of various fields for the purpose of optimum configuration, higher efficiency, lower energy consumption and pollutant emission.

2.1 Polygeneration：the trend of world energy utilization

Throughout the world industrial development and large-scale utilization of fossil fuels increasingly deteriorates environment of the earth. Therefore, almost all

the countries and industries are looking for new systems with less resource loss, higher energy efficiency and lower emission. For example: The Department of Energy (DOE) of US has put forward the Vision 21 energy system.[3] (Fig.1) In detail, the syngas from coal gasification can be used to produce H_2 and H_2 also can be used as the fuel of fuel-cell automobiles. In addition, the syngas put in the combined cycle of high temperature SOFC and gas turbine to generate electricity. As a result, the thermal efficiency could arrive at 50-60%, traditional pollutant emission could be negligible, green house gas emission could be reduced to less than 50%, and economic benefits could be 10 percent higher than that of conventional pulverized coal boiler power plant.

Shell Company has proposed the concept of Syngas Park. In this park, coal or residual oil is gasified and the produced syngas can be used to generate electricity with IGCC, to produce methanol and fertilizer in a "once-through" way and can also be used as town gas[4](Fig.2).

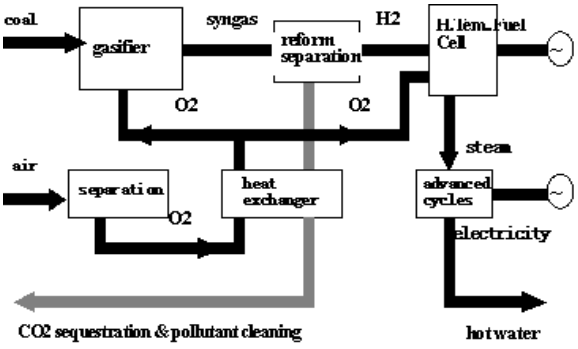

Fig.1 Vision 21 energy system[3]

Some IGCC power stations have been established inside the petrochemical enterprises. They use cheap residue oil, pitch, petrocoke or orimulsion as feedstocks to produce syngas. Syngas can either be used as raw materials for production of value–added chemicals or to provide electrical power and steam for the production processes. This makes the production of electricity and heat closely incorporated with chemical production processes, and decreases the costs for both chemicals and electricity. Up to now, dozens of such facilities have been put into operation all over the world, and more are under development. One typical example is the facility in Italian ISAB Company

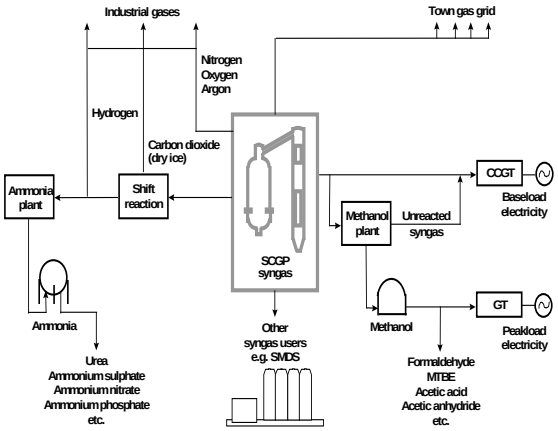

Fig. 2 Syngas Park Concept by Shell Company[4]

with a power output of 512 MW.

The above examples show that many developed countries are seeking efficient solutions to resource shortages and environment pollution problems. However, due to the traditional separation of different sectors, various sectors are looking for optimal solutions in its own field. Actually, these optimal solutions can hardly be the best for society as a whole. Polygeneration tends to be a highly flexible and optimal integration of resource/energy/environment systems and it is by all means to benefit society, and break up the existing separation of different industrial sectors.

2.2 The benefits of polygeneration system

The base case for comparison is the stand-alone production of power, heat, methanol and syngas by conventional power plants, industrial boilers, traditional technology for methanol production, and coal gasifiers correspondingly. The outputs are respectively 400 MW_e, 400 MW_{th} and 400MW equivalent.

Compared with stand-alone production, quad-generation of these four products leads to the following benefits: reduction of capital investment by 38 percent, cost for unit energy by 31 percent, and coal consumption by 22.6 percent[5] (see Fig.3).

Though the above-mentioned results are rather simplified and should be adjusted according to the different situations, the potential benefits of polygeneration system are obvious.

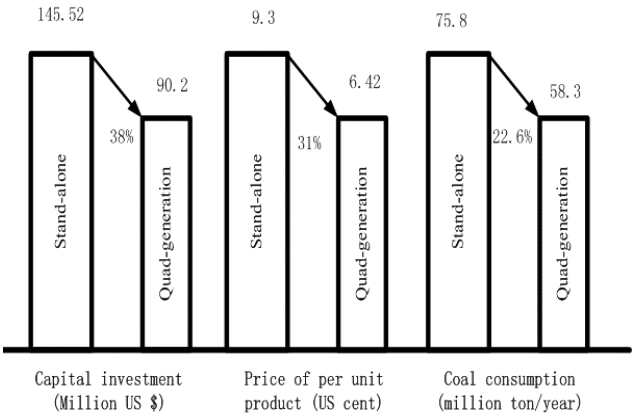

Fig. 3 Benefits of investment, energy consumption and environment for quad-generation

3. Superclean polygeneration energy system of iron and steel industry

The idea of polygeneration based on coal gasification is to be extended to the field of iron and steel, resulting in a lot of problems corresponding to new thoughts and solutions.

3.1 COREX evolution strategy based on Polygeneration

3.1.1 COREX smelting reduction technology.

The main materials of conventional blast furnace are coke and sinter, meanwhile, coking and sintering are major segments resulting in high energy consumption and pollution. On the other hand, the smelting reduction COREX iron-making technique has become an issue of increasing interest in the field of metallurgy. Several factors contribute to the consequence, in the first place, COREX does not utilize coking coal at all; besides, the equipment flow is simple and the pollutant emission has been reduced greatly. That is, compared with conventional blast furnace, the waste gas and sewage decreases by 90%[6].

3.1.2 New thoughts in COREX development

In spite of the predominance in energy utilization and environment protection, the industrialization of smelting reduction technique such as COREX does not develop as rapidly as expected. As a result of the fact that the coal consumption per ton of COREX is far more than that of conventional blast furnace.

In COREX system, the melter gasifier is actually a special used pure O_2 fired furnace and enormous by-product called medium heat value gas is generated from the casting process. The utilization efficiency of chemical energy stored in coal is so low in COREX iron-making that nearly half of the incoming energy dissipates by output coal-gas in terms of chemical energy.

On one hand, the coal consumption of COREX would be much higher than that of conventional blast furnace because of lower energy utilization efficiency, which constrains the promotion of COREX. On the other, the gasification part of both Integrated Gasification Combine Cycle（IGCC）power plant and polygeneration system account for a comparatively high percent. Taking an operating IGCC power plant for instance, the investment of gasification section is 42%-47% of total. As a result, the essential factor to promote polygeneration system is to produce feed gas economically.[2]

Within the local area of metallurgy industry, emphasis used to be put on the matching of COREX melter gasifier and the reducing gas of reduction shaft so as to reduce the outgoing energy as possible. But the result is not so ideal as expected. As a matter of fact, the key to energy utilization is using COREX by-product of coal-gas effectively.

The Sulfur content percentage of COREX by-product of coal-gas is lower, while the heat value is much higher than that of conventional blast furnace gas. The polygeneration solutions can be in the forms of chemical industry combination, Direct Reduction Iron (DRI) and supplying heat and steam. The net greenhouse gas emission of this system is quite different from that of conventional blast furnace, especially when COREX process is combined with an advanced IGCC. [6] As we can see, the unit CO_2 emission of polygeneration system only equals to 60% of that of conventional blast furnace.

Promoting the polygeneration strategy to the frontier of iron and steel technology and coupling COREX process into the integrated metallurgy-power-chemical polygeneration system are feasible. As a result, the energy

efficiency optimizing objective can be reached within the whole large system. Meanwhile, the polygeneration system can be of the optimum environment benefit. Because COREX system is expected to be not only a metallurgic materials producer, but also an energy conversion unit to output much more low-sulfur gas with higher heat value. It is an absolutely feasible new idea to establish the next generation of iron and steel co-enterprise.

3.2 Coal-gas Byproduct polygeneration strategy of conventional enterprises

In light with the maturity of smelting reduction iron-making technique, the conventional process marked with blast furnace-converter-rolling mode will be carried out by 2020 in China. The increasing pulverized coal injection reduced the coke consumption and pollutant emission to some degree and got better energy conservation benefit as well. The medium and large-sized iron and steel group has made some progress in recycling and reusing the coal-gas of coke, blast and converter furnace.[1]

In general, however, the current research work is resting on the level of local conservation and consumption reducing in local equipment of iron and steel area. For example, regardless of the gas heat value improvement of furnace roof, the reduction of utility value of by-product of coal-gas generated by blast furnace is over emphasized in the following aspects--improved operation, better material and updated equipment to reduce unit energy consumption. This is a local effect rather than the optimum solution from the point of integral benefit.

The idea of polygeneration advocates that the equipment potential of such special gasifiers such as coke oven, blast furnace and converter should be made full use so as to increase both the quantity and quality of coal-gas by-product. The new development thought of iron and steel co-enterprise is also proposed.

The coal-gases of converter and coke oven are individually rich in CO and H_2, combination of which results in the ideal material to synthesize MeOH or DME. MeOH or DME can serve as substitution for gasoline and diesel oil to be strategic liquid fuel.[7]l

Taking iron and steel co-enterprise of 8 million ton for instance, suppose that the converter coal-gas byproduct output per day is about 4.176MNm^3/d; the composition of converter is: CO：69％，H_2：1%，$CO_2+N_2+O_2$; among this, the valid quantity is CO＋H_2：2.92MNm^3/d; theoretically, the gas consumption to produce one ton MeOH is 3000 Nm^3 (set conversion ratio to be 70％) and the gas consumption to produce one ton DME is 4170 Nm^3; the gas utilization ratio is 80％.

Consequently, the yield of MeOH per year is200,000 tons, let unit price be $305, so the output value can be $85.40 million; as to DME, the corresponding data are: $430 and $86 million respectively, which are considerable.

3.3 Superclean polygeneration system of iron and steel enterprises

Based on this thought, the iron and steel co-enterprises produces clean and low-cost metallurgic materials. This can be realized through constructing new generation process flow or improving existing state of the art. Besides, they can serve as a high efficient and clean energy conversion system. That is to say, in addition to meet the need of its own, this system also supplies chemical and energy products such as coal-gas, electricity, heat, liquid fuel (as petroleum substitution) and H_2. With the maturation of economic and technical development including CO_2 burying storage and processing, the iron and steel co-enterprise is expected to be eco-industry process and green polygeneration energy system. The system is of quasi-zero emission, superclean and low environment load.
The idea of polygeneration can be introduced to overpass the division among the individual sectors such as electric power, chemical and metallurgic engineering. The future superclean polygeneration energy system of iron comprehensive optimization, which is a highly flexible and cross-sector integrated system of resources, energy and environment. Fig.4 is its basic framework. The main points are:

1) The conventional blast furnace or COREX Melter Gasifer , coke oven and converter are to serve as energy conversion equipment, special gasifiers. After cleanup and purification of syngas, elementary sulfur could be obtained as a by-product.

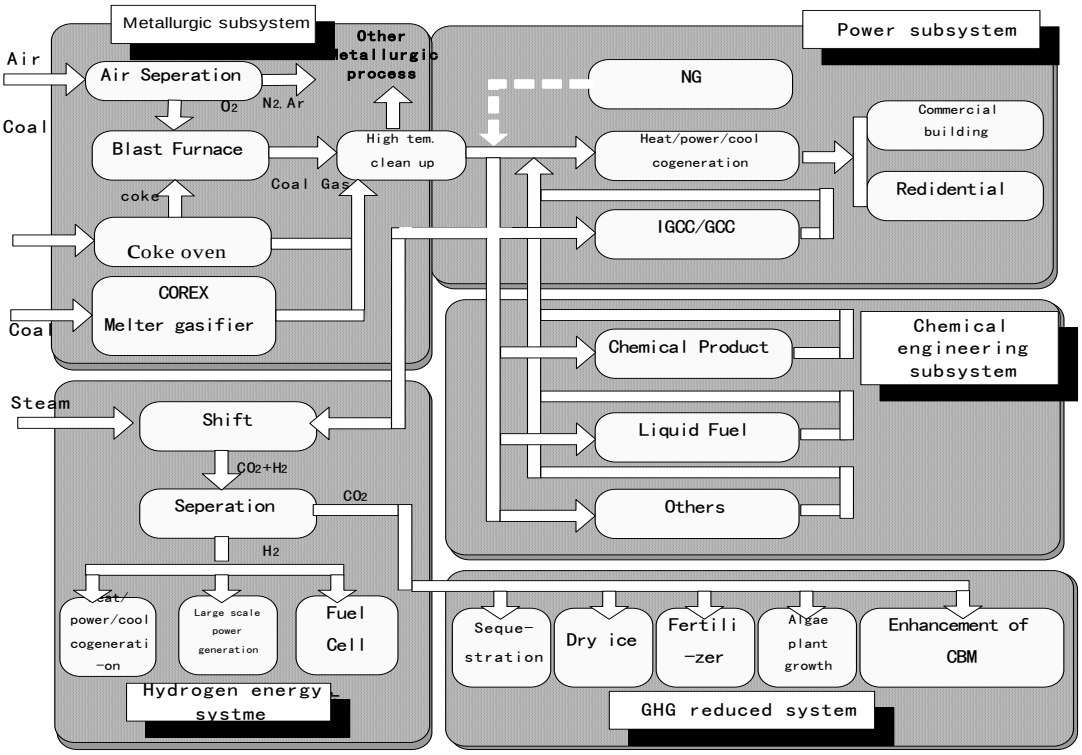

fig. 4. Future polygeneration system model of coal-gas by-product

2) There are diverse ways of utilization for obtained syngas:

* Town gas for cooking and heating, for distributed power, heat and cooling co-generation.

*Large-scale power generation (fuel cell or gas/steam combined cycles)

* Methanol production via the “once-through” liquid phase reactor

* Liquid fuel production (synthetic fuel and diethyl ether) via the “once-through” liquid phase reactor

* Other chemical products (NH_3, urea, middle distillate)

The other part of syngas can be reformed to produce H_2. With the development of PEM fuel cell technology, H_2 can be used as fuel for vehicles and solve the transportation emission of large cities eventually, i.e. creating near zero emission. From the long-term point of view, H_2 as the energy carrier could be used as the cleanest fuel for distributed power, heat and cooling co-generation and for realizing local zero emission as well.

3) The treatment of separated CO_2

When the combustion process is properly controlled, burning of cleaned syngas causes much less pollution than conventional power plants with direct firing of coal. Therefore, the key issue will be the treatment of greenhouse gas CO_2. For the proposed polygeneration system, because the separated CO_2 is nearly pure (99%) instead of mixed with 75% nitrogen in the flue gas of the conventional power plant, CO_2 could be used as feedstock for different products, such as urea, dry ice, etc. (The new development of inorganic membrane is very promising as a more efficient and economic way for CO_2 separation[8]). It can also be used for enhancement of plant growing and other industrial purposes. There are also a lot of other ways for CO_2 sequestration, to deep sea, to depleted oil and gas fields or to saline aquifers. Surely these concepts are only in the preliminary stage of development, the detailed technical, environmental and economical assessment should be conducted. But anyway, pure CO_2 will be much easier to be treated than CO_2 in the flue gas of conventional power plants.

4) Close inter-coupling of production processes

The core of the proposed polygeneration system is the 4)close coupling of the production processes of different products. For instance, after passing through the "once-through" liquid phase reactor to produce methanol (or DME), the unreacted syngas could be directed to IGCC for power generation instead of subsequent separation and recycling to the reactor again as it is in conventional stand-alone methanol production. Therefore, the capital investment, maintenance cost and environment impact will be significantly reduced, and consequently the cost of these products could be reduced as well. Furthermore, because of the co-production, the "peak and valley" of each product (especially power generation) could be adjusted more easily according to the demand.

4. Conclusion

The polygeneration strategy based on coal gasification is an inevitable trend for future sustainable development of energy industry in China. Based on this, in this paper, the following three new thoughts are proposed to solve the problems of energy utilizing efficiency and pollution emission:

1）In line with the main problems in smelting reduction iron-making, COREX polygeneration strategy of coal-gas by-product is proposed. Provided that COREX process is to be analyzed and discussed within a combined metallurgy-power-chemical polygeneration system; and then comes an optimum economic and environmental solution. All the above makes it feasible to establish the next generation process of iron and steel co-enterprise.

2）Making full use of potential benefits of special gasifier such as converter, blast furnace and coke ovens, a new development idea of coal-gas polygeneration of iron and steel enterprises is proposed. It makes a break-through in the theory of Energy Conservation and Loss Reduction.

3）The concept model of future superclean iron and steel polygeneration system is established, and the resultant sectors are not only high-quality, low-cost iron and steel producers, but also expected to be eco-industry process and green polygeneration energy system with quasi-zero emission, supercleaning and low environment load.

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