Consideration and Practice of Science, Technology and Strategy for Minimizing CO₂ Emission in Chinese Steel Industry

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In order to minimize CO₂ emission from iron and steel-making processes to abate greenhouse gas impact, the considerations and some practice of science and technology as well as its strategy completed and ongoing in Chinese steel industry are summarized. Two available ways for the minimizing in China so far:

(1) Minimizing carbon-consumption (fossil energy-saving) in all the processes of steel industry which is the most realizable measure for reducing CO₂ emission.

(2) To look for new alternative reaction medium in the processes where producing more CO₂ like H₂ in blast furnace etc and new processes for iron and steel making which discharge less CO₂.

Some new ideas like macro-based measures are put forward for minimizing CO₂ emission in steel industry.

KEY WORDS: steel industry, CO₂ emission, strategy, science and technology.

1. Greenhouse gas and global warming

Sweden scientist Svante Arrhenius put forward the conception of "Greenhouse effect" in 1896. Since then the concentration of CO₂ increased 25% in the past 100 years and the global average temperature increased (0.3—0.6) °C and 70 years later the temperature of Earth will increase (2—5) °C. Meteorologists said, "Greenhouse effect" is to keep the temperature on a certain extent for the Earth and the biology habitable originally. The Earth would be a "Ice Earth" with an average temperature of -18°C if there is not a suitable layer of "greenhouse gas" covering the Earth while recent Earth average temperature is +15°C. But when the concentration of CO₂ increases continuously after the industry quick develop period, the function of "greenhouse gas" goes to the reverse direction—makes the Earth too warm and results in a series of problems which let more and more people worry about and work for it.

The atmosphere on Earth consists of hundreds kinds of gas and dust in which oxygen, nitrogen and argon are the main composition which account to 99.96% and CO₂ is 360 ppm, CH₄ is 1.75 ppm, NO₂ is 100 ppm, both SO₂ and H₂S are 20 ppb etc. Basically, all the gases which consist of multi-atom and unsymmetrical double-atom gases (like CO₂, H₂O, SO₂, CH₄, NO₂, O₃, CFCS, HFC, PFC, SF₆ etc.) are greenhouse gas from the point of view: radiation heat transfer due to their absorption of the heat from sun and from Earth radiation which heating the atmosphere to a certain extent. And all the gases which consist of single atom and symmetrical double atoms (like H₂, O₂, N₂ etc.) are not greenhouse gas which are called "Transparency gas" for radiation heat transfer, because they do not absorb heat from sun and the Earth.

Different greenhouse gas has different ability for absorbing heat from its outside environment, which can be seen obviously in the following coefficients of absorbing heat $A_i$:

$$A_{CO₂} = \varepsilon_{CO₂} \times \frac{T_g}{T_w} \times 0.65$$
$$A_{H₂O} = \varepsilon_{H₂O} \times \frac{T_g}{T_w} \times 0.45$$
$$A_{SO₂} = \varepsilon_{SO₂} \times \frac{T_g}{T_w} \times 0.5$$

Where: $\varepsilon$—radiation rate
$T_g$—temperature of gas
$T_w$—temperature of solid wall

Among the greenhouse gases, CO₂ has not the highest ability of "greenhouse effect" according to the above formula (under the same temperature and concentration, N₂O and CH₄ are the two top level), but so far CO₂ is the biggest greenhouse gas due to its emission volume absorbing huge amount of infrared radiation than the other greenhouse gases (Fig.1) and the density of CO₂ is heavier than air by 1.53 times which is easier to cover the Earth and influence the near-Earth climate directly. All these gases control the flow of natural energy...
through the climate system.

Fig. 1 Role of CO₂ in Enhanced Global Warming from 1990 Emissions

2. CO₂ Emission and General Abatement Strategy in Chinese Steel Industry

Normally, general “greenhouse effect” abatement and mitigation strategies are in the following 3 ways:

1. Reduce the amount of CO₂ producing
2. Remove and utilize CO₂ from the processes
3. Store CO₂ in somewhere e.g. deep-sea, underground in oil field etc.

All the iron and steel making processes are based on carbon-consumption energy so far (fossil fuel is 95% of the total in China in which coal make up 75%, energy structure in Chinese steel industry 1999: coal: 70.00%, coke coal: 48.00%, fuel coal: 22.00%, electricity: 26.80%, heavy oil: 3.00%, nature gas: 0.20%) and most energy for the processes comes from carbon oxidation reaction, all the carbon oxidation reaction will produce CO₂ by the following basic reaction more or less:

\[ C + O_2 \rightarrow CO_2 + \text{Thermal energy} \]

It means 1.0 kg carbon will produce maximum 3.76 kg CO₂ and also means that save 1.0 kg carbon will reduce maximum 3.76 kg CO₂ from the above formula. That is why United Nations Environment Programm (UNEP) said: Energy-saving is the strongest measure for environment protection. So the CO₂ reducing strategy, science and technology transfer to energy-saving strategy, science and technology mainly.

The gross emission of CO₂ in China is 643 million tons in 2000 and steel industry is of 11% of it (according to the percentage of the gross energy consumption to the National amount in 2000).

There are some macro-based ways to abate CO₂ emission for Chinese steel industry so far:

- Decrease iron/steel rate since liquid iron is a energy-rich material(China:0.972(average), Japan: 0.737/t, 1999).
- Increase the continuous casting rate (CCR) to simplify the heating and rolling processes for metal (CCR: 85% 2000 and >90% 2001).
- Improve the quality of raw materials(iron ore, coke etc.)—save additional energy consumption.
- Innovate or simplify the main iron and steel making processes (e.g. mini-mill, developing high efficiency-low cost direct-reduction and smelting reduction processes etc.).
- Enhance the level of equipment for energy and materials consumption.
- Implement "Clean Production" strategy—consider from products design—manufacture—utilization—recycling.

3. Science and Technology for minimizing CO₂ emission in Chinese steel industry

Actually, science and technology measures are micro-based measures for minimizing CO₂ emission. But which processes in steel companies where CO₂ emission is in the top level? According to CO₂ resource—carbon consumption distribution, iron making (50~70%) is the first top one, sintering is the second one (10~15%), coke making and hot rolling are the third one(7~12%). The rest are cold rolling, steel making and others(e.g. transportation etc) respectively. So we can also define CO₂ reduction science, technology and strategy as energy-saving science, technology and strategy.

(1) Science and technology for saving carbon consumption in all processes of steel industry for minimizing CO₂ emission

So far reducing CO₂ emission is mainly focus on energy-saving in steel industry which could be seen in the following formula (from the report of "National Energy Options for Reducing CO₂ Emissions", Vol.1, National Energy Research Foundation ECN, 1993):

\[ CO₂ = \frac{CAP × GDP × TPER × TFOS × CO₂}{CAP × GDP × TPER × TFOS} \]

Where:

- CAP = Population
- GDP = Gross Domestic Product
- TPER = Total Primary Energy Consumption
- TFOS = Fossil Primary Energy Consumption

It could be seen that fossil energy consumption and primary energy requirements are the main contributors for CO₂ emission (under the same population and gross domestic product).

In general, all the energy saving technologies could be regarded as the ways to reduce CO₂ emission e.g. TRT(before 2005, all the blast furnaces(volume larger than 1000m³) will install TRT device), CDQ( will build more than 20 sets in the coming 5 years), PCI(National average PCR will be up to 100kg/THM before 2005), BOF gas
recovery (get to the level of 70M3/t before 2005), iron/steel rate (more than 0.93, 1999), continuous casting rate (more than 80%, 2000 and more then 95% 2005), waste heat recovery, high efficiency combustion (like HTAC—high temperature air combustion etc), heat transfer technology, near net shape continuous casting and high temperature air combustion (HTAC) etc which will not be discussed in this paper in details since they were already introduced in many reports.

In Chinese steel industry from 1995 to 2000, 3.7% of average energy-saving per year was achieved and the energy consumption decreased 50 kgce/t each year in the pass 5 years.

The energy consumption distribution in Chinese steel industry showed that iron making process consumed the highest percentage of carbon energy in whole steel making processes. So the CO2 emission from blast furnace would be in very high level and reduce CO2 emission from blast furnaces become one key factor.

New conception for searching the potential of energy-saving: original way to determine the potential of energy-saving depends on the first law of thermodynamics—energy balance and energy efficiency evaluation. It is only a "quantity" conception which is not suitable for different grade of energy. The "Exergy" conception which came from the second law of thermodynamics is good for describing both "quantity" and "quality" of the energy used. The practice results indicated it is good to determine the real potential for energy-saving in different processes.

Chinese government now starts a plan to build up some standard "Energy-saving and Cleaner Production Steel Works" from 2001. The first one has been decided in Jinan Steel Works in Shangdong Province (the details are written in another report) which will be highly benefit for minimizing CO2 emission in Chinese steel industry.

Some researchers in Chinese universities and steel works are now going to initiate a new project for reducing CO2 emission in blast furnace by reducing carbon consumption (lower than the limit: 430 kg carbon consumption/t) greatly in the main chemical reaction and the whole energy system.

(2) Increase H2 content in blast furnace for iron ore reduction reaction:

Another way to reduce CO2 emission is use alternative reaction medium in iron and steel making processes, e.g. increasing H2 content for the iron ore reduction reaction inside blast furnace. There are 4 ways to increase H2 content inside blast furnace:

1) Inject waste plastic into blast furnace:
Inject a certain amount of waste plastic into blast furnace which will decrease 1.5% energy consumption partially due to the slag volume decrease and will reduce 10.5% CO2 emission. Some Professors and industrial researchers are doing some flexibility study by some experiment for it recently and got some interesting results that the H2 content increases up to 12—15% along with the plastic injection into blast furnace.

2) Inject a litter higher amount of nature gas into blast furnace; H2 content could be up to more than 36% in the blast furnace.

3) Inject some amount of pulverized coal especially high volatile coal into blast furnace, and H2 content will be increase inside blast furnace.

4) Increase moisture content in hot blast can also increase H2 content which already practiced in many Chinese blast furnaces. But the H2 content is not so high and it could only be carried out in the blast furnaces which are of higher blast temperature.

The following research work are just being carried out:

- What is the maximum accepted H2 % for blast furnace?
- H2 behavior in blast furnace
- What is the minimum coke consumption under high H2 % condition?
- The effects of high concentration H2 on coke strength under high temperature
- Thermodynamics of water-gas shift reaction on iron ore reduction and coke gasification reaction.
- The effects of H2 concentration on carbon reaction with iron ore
- Gas flow (with high H2 content) in the lower part of blast furnace and so on

(3) Consideration to develop the technologies for CO2 separating, absorbing and storage:
Under ground disposal of compressed CO2 in depleted gas or oil fields or in aquifers and disposal in deep ocean water are considered. The results show that CO2 can be separated, absorbed and stored, but it is much expensive in industry practice use since the concentration of CO2 is too low and the flow rate is too high.

4. Conclusions

(1) Minimizing CO2 emission is a global and National scale system engineering which including society, population, economic developing, law, policy, international cooperation, afforesting, technologies and technology etc.

(2) Minimizing CO2 emission in steel industry so far is mainly focus on fossil energy(carbon energy) saving which including the macro-based measures like:

- Has a suitable global steel productivity (developing other materials which are in low carbon-consumption instead of steel)
- Improve the strength and service life of steel
- Simplified the processes for iron and steel making
- Switch the energy structure
- Improving raw materials quality
- Lower down the rate of iron/steel
- Increase continuous casting rate
- Improving the level of PCR
- Improving the energy-consumption equipment
- Waste heat recovery,
- Waste resources recycling
- Set up energy management system and implement the "Cleaner Production" strategy etc.

(3) Minimizing CO2 emission on micro-based measures which is focus on science and technology scale including:
new evaluation standard for search the potential of energy-saving in a process—"Exergy" analyses, changing some reaction medium e.g. increasing H2 content inside blast
furnace to replace the carbon consumption partially etc.

(4) It is necessary to search some new ways to remove, separate, use and store CO₂ in some appropriate (mainly cheaper) conditions in low concentration CO₂ flue (except afforest).

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