COMPARATIVE ANALYSIS OF BOILER ENERGY EFFICIENCY REGULATION SYSTEM

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ABSTRACT: Industrial boilers are increasingly used with the rapid economic development of our country, with both energy consumption and pollutant emissions ranking second in national industry sector, second only to utility boilers; their coal consumption is far higher than high energy-consuming steel, petrochemical and building material industry sectors, and their pollutant emissions caused to national key cities have exceeded that of utility boilers. In this paper, we focused on the merits and demerits of China’s industrial boiler energy efficiency indicator standards and make suggestions for improvement, specially, China industry boilers energy efficiency standards and regulation. We really think it will great promote China industry boilers energy efficiency progress.

1. INTRODUCTION
Industrial boilers are increasingly used with the rapid economic development of our country, with both energy consumption and pollutant emissions ranking second in national industry sector, second only to utility boilers; their coal consumption is far higher than high energy-consuming steel, petrochemical and building material industry sectors, and their pollutant emissions caused to national key cities have exceeded that of utility boilers[1]. In this paper, we analysis of merits and demerits of China’s industrial boiler energy efficiency indicator standard and making suggestions for improvement: in comparison with foreign practices, to research industrial boilers with different fuels, furnace types and capacities and boiler using units with different management levels in China, analyze the current energy conservation situation, problems and reasons in current operation of industrial boilers, predict the energy conservation potential, and make suggestions suitable to China’s national conditions that can perfect the industrial boiler energy efficiency indicators and evaluation methodology system in combination with the current situation of industrial boiler industry and previous relevant work achievements and by drawing on foreign experience in industrial boiler energy conservation management; analysis and research of impacts of exhaust gas temperature, excess air coefficient and other factors on boiler thermal efficiency and change law thereof, and making suggestions on energy efficiency indicators suitable for Chinese industrial boiler products.

2. COMPARATION OF INDUSTRY BOILERS REGULATION SYSTEM IN CHINA
2.1. Laws and Regulations System
Comparing the boiler efficiency regulations system of the United States, EU and its principal members, Japan and China, the similarity in the regulations and standard system is that such laws and regulations may propose the fundamental requirements according to different levels, then the government authorities introduce regulations on management of energy conservation and emission reduction and
propose the minimum indicators, while the specific technical methods and contents are to be supplemented by the standards or guidelines; in terms of government regulation, professional government authorities will propose law-based regulations to implement the details and minimum indicators, while the local governments or member state will propose more detailed plan to supervise the industry or enterprise, so as to reach the target of more detailed level-to-level progress of regulations and the clearer leveled supervision.

2.2. Energy Efficiency Indicators of Boiler.

|                                | CHINA GB24500 | CHINA TSG G002 | USA | EU | JAPAN |
|--------------------------------|---------------|----------------|-----|----|-------|
| Energy efficiency indicator of new boiler products | Rated load thermal efficiency | Rated load thermal efficiency | /   | Average value of thermal efficiency under different loads | /   |
| Energy efficiency indicator of in-service industrial boiler | /             | It is generally greater than 90% thermal efficiency limit of the new product | Annual average thermal efficiency | Thermal efficiency under different loads | /   |
| Energy efficiency indicator of boiler system | /             | /              | Energy consumption per unit heat output | /   | /    |
| Thermal efficiency curve       | /             | /              | /   | Requirement | /    |
| Exhaust gas temperature indicator | /             | Limit value   | /   | /            | Limit value Target value |
| Excess air coefficient         | /             | Limit value   | /   | /            | Limit value Target value |

Figure 1. Comparison of Energy Efficiency Indicators among Different Countries

We can come into the following conclusions through collection and research of energy efficiency indicators of the United States, the European Union and Japan as well as the comparison between the collected indicators with those in China.

BOILER EFFICIENCY INDICATORS IN CHINA: the boiler efficiency indicator is the measured value of thermal efficiency under rated load, the energy efficiency level may be divided into Level-I, Level-II and Level-III according to the boiler type, including layer-burning boiler, circulating fluidized bed boiler and oil (gas)-fired boiler, and the fuel type, including coal, oil and gas; fuel thermal value adopts the received base low heat value; the efficiency indicators of in-service boiler are to be formulated and shall not be less than 90% of the efficiency indicators of boiler new products[2,3]; the efficiency indicators of boiler system are to be formulated; limit value is to be set for exhaust gas temperature and excess air coefficient of boiler.

BOILER EFFICIENCY INDICATORS IN THE UNITED STATES: the requirement of the United States on boilers is annual average fuel efficiency, which can distinctly reflect the operating conditions of the user; fuel may be divided into oil, gas and other fuels, the fuel heating value adopts the received base high heat value; due to the differences between China and the United States, the number of hot-water boiler is limited, so the requirement on boiler system is mainly to evaluate the steam system according to ASME Standards[4], so as to figure out the unit heat output and energy consumption, identify the energy-saving opportunities and conduct the energy conservation transformation; exhaust gas temperature and excess air coefficient of boiler are to be specified.

BOILER EFFICIENCY INDICATORS IN EU: the efficiency indicators of boiler new products of main countries in EU are weighted average of thermal efficiency under different load conditions without distinction between the boiler type and fuel type, while condensing boiler and non-condensing boiler are to be distinguished; fuel thermal value adopts the received base higher and low heat values; the efficiency indicators of industrial boiler are thermal efficiency of boilers under different load
conditions for evaluation on the operating conditions of the boiler[5]; boiler efficiency indicators are to be formulated, while annual energy conservation requirements exist for boiler user; exhaust gas temperature and excess air coefficient of boiler are to be specified; in addition, EU has formulated specific regulations on the heat loss due to exhaust gas of boiler, regulating the heat loss due to exhaust gas shall not exceed 9%[6].

BOILER EFFICIENCY INDICATORS IN JAPAN: the boiler efficiency indicators in Japan are different from those in China, the United States and the European Union, such indicators are not thermal efficiency standards, but selecting exhaust gas temperature and excess air coefficient as energy efficiency control value, the boiler type may be divided into solid fuel (solid-fuel boiler may be divided into fixed bed and fluidized bed), liquid fuel and gas fuel in terms of fuel, and the exhaust gas temperature and excess air coefficient may be divided into benchmark value and target value, and it makes no distinction among boiler new products, in-service products and boiler system[7-9].

2.3. Comparison of Test Methods
Through collection and research of data on energy efficiency indicators of the United States, the European Union, Japan and China as stated above, the main comparison on the test methods of boiler energy efficiency is shown in Fig 2 as follow.

| CONTENT                  | CHINA                      | USA                      | EU                        | JAPAN          |
|--------------------------|----------------------------|--------------------------|---------------------------|----------------|
| Test method              | Direct balance method      | Direct balance method or indirect balance method | Direct balance method or indirect balance method | /              |
|                          | Direct-indirect balance method | Indirect balance method |                          |                |
| Calculation method of thermal efficiency | Average value of direct and / or indirect balance thermal efficiency | The indirect balance method is recommended to calculate the thermal efficiency | The indirect balance thermal efficiency is recommended | The indirect balance thermal efficiency |
| Fuel heat value          | Low heat value             | Low heat value           | High heat value           | High heat value or low heat value |
| Times of test            | 2 times                    | 2 times                  | At least 1 time           | At least 1 time |
| Uncertainty analysis     | /                          | Error analysis           | Uncertainty analysis      | Uncertainty analysis |

Figure 2. Comparison of Energy Efficiency Test Methods for Boilers in Different Countries

Except for Japan, the boiler thermal performance test principle is basically the same in different countries with little difference in test methods. There are two main differences between Chinese and foreign standards:
1. Using low calorific value in the efficiency calculation of condensing boiler or condensed gas fired boiler with low exhaust gas temperature is not accurate;
2. Uncertainty analysis is not made for test calculation results.

In theory, Chinese standard and ASME standard (2010 Edition) shall be the most accurate, followed by the ASME standard (1964 Edition), and the EU standard model is the most rough. However, the test results of EU standard can be in good agreement with the ASME standard. One of the main reasons is that for tests in accordance with the EU standards, the test personnel are more likely to link them with production practices, and pay more attention to the boiler operation conditions, parameters such as nature of fuel.
3. Thinking on Advanced Methods of Energy Conservation and Environmental Protection for Industrial Boilers Abroad

1. Specific requirements of foreign government departments (such as the United States Department of Energy, the Environmental Protection Administration) for energy conservation and environmental protection will support the corresponding measures and preferential policy. Similarly, the EU Member States will also introduce appropriate tax or subsidy policy when setting their own regulations on the basis of the EU directive so that the cohesion between regulations and policies will be more closely and easier to perform;
2. Foreign regulations and policies are not unchanged for a long time, but continuously improved to embody equipment and technology level. At the same time, relevant policy promotion and reward system are in continuous improvement to ensure the incentive system can achieve the desired effects;
3. Comparing the boiler energy conservation environmental protection indicators in domestic and foreign energy efficiency regulations and standards, there are only mandatory indicators in China such as energy efficiency and emission limits, but the United States and EU indicators are classified as voluntary and mandatory indicators, in which most of using units can achieve the mandatory indicators directly or through the relevant regulations and standards formulation methods or models, but it is relatively difficult to achieve voluntary indicators. They give clear gaps between the advanced and the backward and provide time for the laggard to narrow the gap so as to realize the effect of all-round progress;
4. Domestic regulations and standards for the management and the indicators are for different types of boiler units. However, the management of the United States and the European Union is more in the category of industry or enterprise itself. On one hand, it highlights the system concept to measure and enhance the operation level through the input-output ratio better. On the other hand, it can play the guiding role of regulations and standards according to industry characteristics, without coming apart from the reality.
5. Combined with boiler’s energy efficiency indicators of environmental protection, the United States and the European Union both closely combine the boiler’s energy conservation and environmental protection indicators, which is consistent with the operating characteristics of the boiler. The performance of energy conservation and environmental protection can only be proved by achieving the standards of energy efficiency and environmental protection under specified conditions. Otherwise, simply considering the energy or environmental problems may cause the situation that emissions are increased to achieve qualified energy efficiency or the qualified emission is achieved at the expense of energy efficiency. The actual energy conservation and environmental protection performance of the boiler cannot be effectively evaluated, which is not conducive to the progress of energy conservation and environmental protection.
6. According to specific energy conservation and environmental protection indicators of boilers, particular emphasis is put on the use side abroad. For example, different environmental indicators based on heat input/output are stipulated in the United States to guide the use units to solve and concern emissions during operation. Japan sets indicators for exhaust temperature, excessive air coefficient and other major parameters during the daily operation of boiler in energy conservation, and combines with the "leader" system and other modes to regulate the daily operation and management of enterprises.

4. CONCLUSIONS

4.1. Suggestions on Improving Energy Efficiency Indicators and System Evaluation Method of Industrial Boilers In China

Through the comparison of Chinese and foreign boiler efficiency indicators, we can find the regulations for boiler efficiency indicators of national regulations and standards differ from one another. Since the supervision of energy-saving boiler is late in our country and the relevant laws and
regulations of energy conservation system is not perfect, the current Chinese boiler energy efficiency indicators are only defined for new products without clear requirements for efficiency indicator of in-use boilers and boiler systems. By reference to foreign practices, the following suggestions are put forward to promote the development of Chinese industrial boiler efficiency indicators:

ENERGY EFFICIENCY INDICATORS FOR NEW BOILER PRODUCTS:
1. The indicators of new boiler products only consider the rated load, and in the actual operation, most boilers cannot be operated for a long time under rated load, resulting in the indicator value inconsistent with the actual situation. Referring to the average fuel efficiency in the United States, the weighted average approach of the thermal efficiency under different load is used by the EU. It is suggested to improve boiler efficiency indicator into the weighted average of the thermal efficiency under different load and to form the boiler efficiency curve in order to fully reflect the comprehensive status of the boiler operated under different operation loads;
2. At present, Chinese standards have too single energy efficiency indicators of boiler products, which is only the thermal efficiency indicator and not conducive to the comprehensive evaluation of boiler operation conditions. By reference to the parameters of exhaust gas temperature, heat loss, etc. in EU, Japan and other countries, detailed requirements are given. It is suggested to propose the limits of exhaust gas temperature and excess air coefficient under different loads, or take such limits as preconditions that the thermal efficiency of the load achieves the standard;
3. The classification of the thermal efficiency of gas fired boilers needs to be further improved, and the condensing and non-condensing boilers shall be clearly distinguished.

ENERGY EFFICIENCY INDICATORS FOR IN-USE INDUSTRIAL BOILERS:
1. The in-use industrial boiler indicators shall be capable of reflecting the ratio between the unit energy consumed and heat output in unit time in accordance with the provisions of the production and operation of the enterprise. Annual average thermal efficiency indicators are established to combine with enterprise production; 2. For in-use boilers, operation parameters such as exhaust gas temperature, excess air coefficient shall evaluate the operation conditions of boilers according to the efficiency curve of boiler products by reference to the boiler efficiency indicators and thermal efficiency of new products; 3. The in-use boiler classification shall be optimized and adjusted. Firstly, capacity division and fuel distinction for coal-fired boilers and fuel gas boilers shall be combined and optimized to encourage small boilers to emulate large boilers in terms of efficiency; secondly, for small layer combustion coal-fired boilers, circulating fluidized bed boilers and oil gas-fired boilers, the thermal efficiency indicators shall be increased based on the actual situation to avoid inefficient boilers appearing in the market.

ENERGY EFFICIENCY INDICATOR OF BOILER SYSTEM:
1. To be clear with the concept and scope of the boiler system and make clear the energy efficiency indicator of boiler system, the output energy of boiler system and the ratio of water, electricity and labor consumption should be taken as energy efficiency indicators to highlight the concept of unit thermal energy output consumption, and the concept of regional energy optimization shall be established to effectively encourage the concept of combined heat and power generation and other energy cascade utilization to optimize China's boiler capacity structure; 2. Using foreign experience for reference, different input-output ratios are set up for different industries and enterprises as indicators; 3. We can consider different regions to set up different system indicators, and compare and revise them according to the industry level or enterprise level in different regions due to the wide territory of China and different energy efficiency conditions in different territories.

BOILER ENVIRONMENTAL PROTECTION INDICATORS: Referring to the energy efficiency indicators of major countries in the United States and the European Union, it can be found that foreign boiler management pays more attention to the boiler environmental protection performances, and the boiler emission indicator limit is more stringent than the energy efficiency indicator. When China's current environmental problems become increasingly prominent, and fog and haze weather continues, as the main source of atmospheric pollutants, environmental indicators for the boiler should be combined with energy efficiency indicators. It is recommended that when using energy consumption
indicator in new boiler products, emission targets of CO, HCL, particulate matter, NOx, sulfide, Hg and its compounds and other pollutants are added and combined with the design, manufacture, operation and other aspects of boilers. Achieve emission standards by putting an end to the way to reduce boiler energy efficiency, or achieve energy efficiency standards by increasing the means of pollutant emissions.

OPTIMIZATION OF TEST AND EVALUATION METHOD: As to the issues indicated in the test and evaluation work at present, there are some effective measure can be taken as follows, firstly, it is recommended to revise the boiler thermal efficiency test and calculation method in the current standard, or formulate boiler energy efficiency test and calculation method, so as to avoid the efficiency deviation of condensing gas-fired boiler caused by using the lower heating value. Secondly, revise the current energy efficiency test method, and add the organic heat carrier boiler contents. Thirdly, prepare the test and calculation method of waste heat boiler energy efficiency, to make up for blanks. Fourthly, revise the test and evaluation regulation and standard of current boiler energy efficiency and add the contents about the evaluation method of boiler energy efficiency.

4.2. Suggestion on China Industrial Boiler Energy Efficiency Indicator and Evaluation System

Compared with the construction condition of Industrial boiler energy efficiency indicator and evaluation system of such countries as the USA, main countries of European Union and Japan, the following perfecting suggestions are proposed as per the boiler's operation and development condition in China:

| LAWS | Special Equipment Safety Law of the People's Republic of China | Energy Conservation Law of the People's Republic of China |
|------|---------------------------------------------------------------|----------------------------------------------------------|
| REGULATIONS | Safety Supervision Rules on Special Equipment | |
| RULES | Procedures of Energy Conservation Supervision of Energy Intensive Special Equipment |
| ISSUED | DRAFTING |
| TECHNICAL SPECIFICATIONS | TSG G0002-2010 Boiler Energy Conservation Technology Supervision Regulations | TSG G0003-2010 Test and Evaluation Rules of Industrial Boiler Energy Efficiency | Energy conservation performance evaluation guideline of industrial boiler | Energy conservation management Rules of boiler system |
| ISSUED | DRAFTING | TO BE PREPARED |
| RELEVANT STANDARDS | GB/T 10180-2003 Thermal Performance Test Code for Industrial Boilers | NB/T 47035-2013 Energy Performance Assessment for Industrial Boilers System | Thermal performance test code for condensing boiler | Energy utilization efficiency indicator and classification for industrial boiler system | Energy conservation standardization management and evaluation rules for boiler system | Full life-cycle economical evaluation guideline for industrial boiler |

Figure 3. System Framework of Boiler Energy Conservation and Environmental Protection Regulation

Firstly, prefect the laws & regulations, speed up to formulate the boiler energy conservation & environmental protection supervision and management method, construct the safety, energy conservation & environmental protection regulatory mechanism of boilers and make unified regulation for the energy conservation & environmental protection work. Secondly, arrange and revise the regulations, revise the boiler energy conservation technology supervision regulations, prefect and supplement the contents related to the boiler energy efficiency indicator and supplement the contents about the boiler atmospheric pollutant emission regulations in accordance with the requirements of the Law on the Prevention and Control of Atmospheric Pollution. Thirdly, in terms of the technical specification, it shall be classified as per regulatory class, test and evaluation class, indicator class and operation and management class. Regulatory specification determines the energy conservation & environmental protection management method, requirements and the minimum indicator; evaluation
specification determines the test and evaluation method for indicator and others; indicator specification further perfects the indicator in the regulatory class. The classification concept can be proposed as per the energy conservation level to introduce the voluntary indicators; Operation and management class is mainly aimed at manufacturing enterprise or applicable department and puts forward the requirements on manufacturing and operation management. or the domestic standards, formulate the boiler energy efficiency indicator standard under different operation loads, including boiler thermal efficiency, excess air coefficient, exhaust gas temperature, heat output energy consumption and the atmospheric pollutant emission standard of boilers, including particulate matter, CO, HCL, NOx, SO2, mercury and its compound as per the classification of boiler product, in-use boiler and boiler system; Prepare the thermal performance test code for condensing boiler and waste heat boiler, revise the thermal performance test code regulation of industrial boiler, domestic boiler thermal efficiency, thermal test method and other boiler test and evaluation standard and amend the operation and management of the power station boiler. Realize the standard integration effect by preparing and revising the three standards, absorb the more reasonable contents in boiler standards of the USA, Europe and Japan during the preparing and revising, so as to align with the international standard.

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