Status and Analysis on Effects of Energy Efficiency Standards for Industrial Boilers in China

Ren LIU a,b, Lili Chen a, Meng LIU a, Qing DING a, Yuejin ZHAO a

aChina National Institution of Standardization, Beijing, 100191, China
bDepartment of thermal engineering, Tsinghua University, Beijing, 100084, China
*Corresponding author’s E-mail address: liuren@cins.gov.cn

Abstract. Energy conservation and environmental protection is the basic policy of China, and is an important part of ecological civilization construction. The industrial boilers in China are featured by large quantity, wide distribution, high energy consumption and heavy environmental pollution, which are key problems faced by energy conservation and environmental protection in China. Meanwhile, industrial boilers are important equipment for national economy and people’s daily life, and energy conservation gets through all segments from type selection, purchase, installation and acceptance to fuel management, operation, maintenance and service. China began to implement such national mandatory standards and regulations for industrial boiler as GB24500-2009 The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers and TSG G002-2010 Supervision Regulation on Energy-Saving Technology for Boilers since 2009, which obviously promote the development of energy conservation of industrial boilers, but there are also some problems with the rapid development of technologies for energy conservation of industrial boilers. In this paper, the implementation of energy efficiency standards for industrial boilers in China and the significance are analyzed based on survey data, and some suggestions are proposed for the energy efficiency standards for industrial boilers.

1. Introduction
The lack of energy resources and low energy use rate become more and more prominent with the rapid economic development of China[1] Industrial boiler is a kind of important thermal power equipment, and China is the largest manufacturer and consumer of boiler worldwide, with huge energy conservation and environmental protection potential. As for energy conservation and emission reduction in China, it is the key work to actively implement industrial boiler energy conservation and emission reduction and improve the energy efficiency of industrial boiler, which is beneficial to the mitigation of energy shortage in China and compliance with the requirements for energy structure adjustment. Preparation of industrial boiler-related energy conservation management policies, regulations and standards is the basis for the implementation of energy conservation plan for industrial boiler.

2. Development of energy efficiency laws, regulations and standards for industrial boiler of china
During the implementation of the World Bank’s promotion project “GEF High Efficiency Industrial Boiler in China” in 1998, nine standards including “JB/T 10094-2002 General Specifications Industrial Boilers” were prepared and revised after absorbing and applying advanced technologies from foreign countries in consideration of national conditions, industrial features and product levels of China, which accelerates the improvement of quality of industrial boilers in China, narrows the gap between advanced
technical levels of foreign countries and plays an active role for the improvement of thermal efficiency of industrial boiler in China, reduction of discharge of air pollutants and promotion of energy conservation and consumption reduction [1,2,3].

In consideration of enormous significance of industrial boiler standards in product performance and energy conservation and emission reduction, National Technical Committee on Energy Fundamentals and Management prepared some standards related to energy conservation management of boiler successively and proposed different levels of requirements on energy conservation and emission reduction from type selection, purchase, installation and acceptance of industrial boiler to fuel management, operation, service and maintenance, e.g. GB/T 3486 Technical Guides for Evaluating the Rationality of Heat Usage in Industrial Enterprise that specifies the technical guides for the reasonable heat usage of enterprises, GB/T 15317 Monitoring and Testing for Energy Conservation of Coal Fired Industrial Boilers that specifies the monitoring items and methods as well as assessment indexes for the energy use of coal fired industrial boilers, GB/T 17954 Economical Operation of Industrial Boilers, GB/T 19065 Economical Operation of Electric Boiler System and GB/T 18292 Economical Operation of Domestic Boilers that specify the requirements, management rules, classification, technical indexes, assessment, etc. for the economical operation of industrial boilers (electric boilers and system, domestic boilers) respectively. In 2007, China National Institute of Standardization and Shanghai Industrial Boiler Research Institute organized experts from boiler industrial to prepare and revise such national standards as GB24500 The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers on the basis of extensive researches, which were implemented since September 1, 2010. As the technical support for the implementation of the Energy Conservation Law of the People's Republic of China, this standard is prepared in full consideration of the macro energy conservation policies and actual conditions of China, as well as the current situation and technical development trends of the boiler industry, with some provisions (allowable values of energy efficiency) adopted as mandatory national standards. In this standard, energy efficiency of industrial boilers is classified into 3 grades with Grade 1 as the highest grade, and the minimum requirements for the thermal efficiency values of all types of industrial boilers under rated operating conditions are specified. It is the standard for evaluating the energy efficiency of new industrial boilers, and its allowable values of energy efficiency are introduced directly in TSG G0002-2012 Supervision Regulation on Energy-Saving Technology for Boilers as the assessment indexes for industrial boiler market access.

The boiler management authority of China attaches great importance to the establishment of laws and standard system for boilers. Regulations on Safety Supervision of Special Equipment revised by the State Council in 2009 specifies energy conservation-related requirements for the design, manufacture, installation, use, repair, renovation, inspection and other links of special equipment with high energy consumption including industrial boiler [4,5]. TSG G0002 Supervision Regulation on Energy-Saving Technology for Boiler, TSG G0003 Energy Efficiency Test Method for Industrial Boiler and relevant technical regulations issued in 2010 further perfect the laws and regulations for energy conservation of boilers. In 2015, TSG G1001 Boiler Design Documents Appraisal Administration Regulation was revised, with relevant requirements for appraisal of boiler design on the basis that effective boiler safety design approval requirements of the original standard are reserved. The design document appraisal is to verify whether the safety and economic performances of boiler design conform to such technical specifications and relevant standards as Boiler Safety Technical Supervision Administration Regulation and Supervision Regulation on Energy-Saving Technology for Boilers.

In 2012, NB/T 47035-2011 Energy Performance Assessment for Industrial Boilers System was prepared under the organization of China Standardization Committee on Boilers and Pressure Vessels, which fully considers the ideas and thoughts for appraisal as stated in ASME EA-1-2008 Energy Assessment for Process Heating Systems, proposes contents and requirements for appraisal of industrial boilers in China, presents the frame for evaluation of energy conversion efficiency of industrial boiler system and components of energy efficiency evaluation of industrial boiler system, and forms the standard system for financial and technical evaluation of industrial boiler system together with other standards for energy audit, heat engineering test of boiler, fans, economical operation of water pumps,
The evaluation involves acquisition and analysis of information about the system design, operation, energy use and operation data of the industrial boiler system, determination of energy efficiency status of the system, identification of energy conservation opportunities, optimization of energy use and performance, as well as suggestions for improvement of energy use, etc.

In 2015, the “Integrated Improvement of Energy Conservation and Environmental Protection of Coal-fired Boiler” was listed as one of important measures to accelerate the air pollution prevention and speed up the development of energy conservation and environmental protection industry. The establishment and implementation of energy conservation regulation and law system for special equipment with high energy consumption, with the energy conservation technical specification and energy efficiency standards for industrial boilers as the basis, will surely promote the comprehensive improvement of levels in design, manufacture, operation and management of industrial boilers, and proposes new and higher requirements for the energy efficiency standards for industrial boilers in China.

| S/N | Standard Number | Standard Name                                                               |
|-----|-----------------|-----------------------------------------------------------------------------|
| 1   | GB24500-2009    | The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers |
| 2   | GB19761-2009    | Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Ventilating Fan |
| 3   | GB18613-2012    | Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Small and Medium Three-phase Synchronous Motors |
| 4   | GB/T 15317-2009 | Monitoring and Testing for Energy Conservation of Coal Fired Industrial Boilers |
| 5   | GB/T 17954-2007 | Economical Operation of Industrial Boilers                                  |
| 6   | GB/T 19065-2011 | Economical Operation of Electric Boiler System                               |
| 7   | GB/T 18292-2009 | Economical Operation of Domestic Boilers                                    |
| 8   | NB/T 47035-2013 | Energy Performance Assessment for Industrial Boilers System                  |

3. Analysis on implementation of energy efficiency standards for industrial boiler in China

With the in-depth implementation of the Reform and Opening-up, China gradually strengthens the policy support for energy conservation and environmental protection. GB24500-2009 The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers and TSG G0002-2010 Supervision Regulation on Energy-Saving Technology for Boilers were issued and implemented successively, which standardize a series of energy serving supervision mechanisms for boilers in terms of boiler design document energy conservation assessment, energy efficiency tests for approved boiler products, regular energy efficiency inspections of industrial boilers in use, and improve the energy efficiency levels of industrial boilers in China. Thus, the industrial boiler design capacity and product quality of China are significantly improved, and the requirements on energy conservation and emission reduction of industrial boilers are satisfied. According to the statistics of the General Administration of Quality Supervision, Inspection and Quarantine of the People’s Republic of China (see Table 2), totally 526,300 sets of boilers are in use in 2001, up to 98.9% of which are industrial boilers, with the annual capacity of 83,000 t/h. With the acceleration of industrialization and urbanization, the energy and heating demands of human beings increase dramatically, so does their demands for industrial boilers. By the end of 2014, the annual output of industrial boiler was up to 1.78 million t/h, 21 times the total output of previous years. However, in China, the proportion of industrial boilers in use reduces slightly, only 98%, and the number of boilers only grows by 12%, about 638,900 sets.
Table 2 Number of Boilers in Use in China (2000-2014)

| Year | Boiler in Use (ten thousand sets) | Industrial Boiler in Use (ten thousand sets) | Annual Output (ten thousand t/h) | Year | Boiler in Use (ten thousand sets) | Industrial Boiler in Use (ten thousand sets) | Annual Output (ten thousand t/h) |
|------|----------------------------------|---------------------------------------------|---------------------------------|------|----------------------------------|---------------------------------------------|---------------------------------|
| 2000 | 52.63                           | 52.10                                       |                                 | 2008 | 57.82                           | 56.88                                       | 22.27                           |
| 2001 | 53.67                           | 52.95                                       | 8.3                             | 2009 | 59.52                           | 58.48                                       | 29.21                           |
| 2002 | 57.26                           | 56.84                                       | 9.2                             | 2010 | 60.73                           | 58.47                                       | 33.63                           |
| 2003 | 56.24                           | 55.65                                       | 11.4                            | 2011 | 62.03                           | 61.06                                       | 41.33                           |
| 2004 | 57.27                           | 56.63                                       | 13.4                            | 2012 | 63.53                           | 62.40                                       | 43.93                           |
| 2005 | 55.38                           | 54.60                                       | 16.29                           | 2013 | 64.12                           | --                                          | 51.27                           |
| 2006 | 54.31                           | 53.45                                       | 17.51                           | 2014 | 63.89                           | 62.50                                       | 55.81                           |
| 2007 | 53.41                           | 52.44                                       | 20.85                           |      |                                 |                                             |                                 |

Fig. 1 Statics of Number of Industrial Boiler in Use, Annual Output and Consumption of Raw Coal in 2000-2014

Fig. 1 is the statistical chart of number of industrial boiler in use, annual output and consumption of raw coal in 2000-2014. It can be seen from the figure that the number of industrial boiler in use and the variation trends from 2000 to 2014 are basically the same. Within the statistic years, the annual constant number of industrial boiler grows rapidly. The red line indicates the trends of consumption of raw coals from 2009 to 2014, while the blue line indicates the predicted annual consumption of raw coals. It can be seen after comparison that the implementation of *The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers* since significantly pushes the energy consumption of industrial boiler in China. Meanwhile, it is shown in the figure that the total number of industrial boiler increases a little in spite of the continuous growth of the annual constant number of industrial boiler, which demonstrates that the implementation of the national standard of *The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers* does not limit the development
of boiler manufacturers, on the contrary, the production of boilers maintains relative good growth promoted by the economy.

3.1 Energy Efficiency of Approved Products (Rated Operating Conditions)

Efficiency test data of 4,102 sets of approved industrial boilers from 2012 to 2015 published on the Approved Boiler Information Release Platform of the General Administration of Quality Supervision, Inspection and Quarantine of the People’s Republic of China is sorted and classified for statistical purpose. According to the statistics, coal-fired boilers still occupy the largest proportion, up to 44.20%, followed by gas-fired boilers (29.88%) and biomass boilers (16.35%) that rise remarkably. Obviously, industrial boilers in China are mainly of “coal-fired” type, which are the key for energy conservation and environmental protection.

![Fig 2. Types and Number of Industrial Boiler](image)

It can be seen from Fig. 3 that coal-fired boiler consuming soft coal accounts for 90%. The average thermal efficiency of this kind of boiler is 75~85%, and the large the boiler capacity, the higher the thermal efficiency, even 90% for some large-capacity boilers. Take layer-burning boiler consuming Class II soft coal as example, the average thermal efficiency of this kind of boiler is 75~83%, to be specific, 75.68% for those with D<1t/h (or D<0.7MW), 78.5% for those with 1 t/h≤D≤2 t/h (or 0.7MW≤D≤1.4MW), 80.02% for those with 2 t/h≤D≤8 t/h (or 1.4 MW≤D≤5.6 MW), 80.95% for those with 8 t/h≤D≤20 t/h (or 5.6 MW≤D≤14 MW), and 82.58% for those with D>20 t/h (or D>14 MW). It can be analyzed from the test data that 8 out of 1,320 sets of boilers cannot satisfy the requirement on allowable values of energy efficiency, while the vast majority (99%) of boilers can meet such requirement. 24% and 3% of boilers can meet Class 2 and Class 1 energy efficiency as stipulated in GB24500-2009 respectively.
The coal-fired boiler consuming blind coal accounts for 4%. The average thermal efficiency of this kind of boiler is 74–85%. Take layer-burning boiler consuming Class II blind coal as example, the average thermal efficiency of this kind of boiler is 73–82%, to be specific, 73.98% for those with D<1t/h (or D<0.7MW), 78.78% for those with 1t/h≤D≤2 t/h (or 0.7MW≤D≤1.4MW), 78.2% for those with 2t/h<D≤8t/h (or 1.4MW<D≤5.6MW), 79.41% for those with 8t/h<D≤20t/h (or 5.6 MW<D≤14MW), and 81.78% for those with D>20t/h (or D>14MW). It can be analyzed from the test data that 1 out of 75 sets of boilers cannot satisfy the requirement on allowable values of energy efficiency, while the vast majority (99%) of boilers can meet such requirement. 80% and 17% of boilers can meet Class 1 and Class 2 energy efficiency as stipulated in GB24500-2009 respectively.

The statistical data also involves 67 sets of fluidized bed boilers, 24 sets consuming Class I and II soft coal, 33 sets consuming lignite and 10 sets consuming other fuels. Over 98% of CFB boilers satisfy the requirement on allowable values of energy efficiency in GB24500-2009, and 22 sets and 23 sets meet the Class 1 and Class 2 energy efficiency requirements respectively. The average thermal efficiency of CFB boiler is 83–89%, and the large the boiler capacity, the higher the thermal efficiency, even 90% for some large-capacity boilers. The average thermal efficiency of lignite fluidized bed boiler is about 88%, 9 and 11 out of 33 sets of boilers satisfy the Class 1 and Class 2 energy efficiency indexes respectively. There are 4 sets of biomass boilers with the capacity less than 20t/h and thermal efficiency of over 88%.

It can be seen from above-mentioned data that industrial boilers with high energy consumption and low energy efficiency are knocked out in design after implementation of The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers.

3.2 Energy Efficiency of Boilers under Operating Conditions
In this paper, data about the energy efficiency tests for boilers in use under operating conditions supported by local finance in 2012 is collected. It is analyzed from the data that, currently, boilers used by enterprises are mainly chain-grate boilers (over 70%), which mainly consume Class II soft coal. Fluidized bed boilers are extensively used as well, but are commonly used as large-tonnage and large-capacity industrial boilers.
Fig. 4 Comparison of Measured and Standard Thermal Efficiencies of Coal-fired Boilers in Use

Fig. 4 shows the operation energy efficiency data of a large number of chain-grate boilers in use. It can be seen from the figure that the solid text box indicates the measured operation efficiency of the boiler, while the red break lines up and down indicate the variation of test values of different equipment. Within the capacity range of different boilers, the operation efficiency basically satisfies the specified value for operation efficiency of boilers as stipulated in TSG G002-2010 Supervision Regulation on Energy-Saving Technology for Boilers and relevant documents of Special Equipment Bureau, AQSIQ, but is lower than the limited value for thermal efficiency (i.e. rated efficiency of boiler) in GB 24500-2009 The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers. In particular, when D<8t/h, the operation efficiency can only basically satisfy the energy conservation standards and operation regulations. In addition, there is still significant gap between designed efficiency under rated conditions and the actual operation efficiency (blue area). The average load of the boiler system in operation is indicated in asterisk. It can be seen from the figure that, during operation, the measured boiler efficiency is obviously higher than the average load of the boiler system and the operation efficiency of the boiler is still higher than the thermal efficiency value tested in actual operation. Most boilers are in low-load operation, which results in idle operation and lower average operation load. See the table below for the operation loads of boilers tested.
Table 3 Comparison of Thermal Efficacy of Coal-fired Chain-grate Boilers under Different Loads

| Boiler Capacity D (t/h) | Boiler Load Rate (%) | Operation Efficiency (%) | Lower heating value of fuel as received basis Qnet.v.ar (kJ/kg) |
|------------------------|----------------------|--------------------------|--------------------------------------------------------------|
|                        | <20                  | 20~40                    | 40~0                                                         | 60~80          | >80 |
| 1≤D≤2                  | --                   | 70.12                    | 69.15                                                        | 70.64          | 69.12|
|                        |                      |                          |                                                              |                |     |
| 2<D≤8                  | 67.19                | 67.90                    | 69.28                                                        | 71.49          | 71.98|
|                        |                      |                          |                                                              |                |     |
| 8<D≤20                 | 65.55                | 71.21                    | 75.41                                                        | 75.89          | 76.99|
|                        |                      |                          |                                                              |                |     |
| D>20                   | --                   | 82.66                    | 83.54                                                        | 83.47          | --  |
|                        |                      |                          |                                                              |                |     |

The coal-fired industrial boilers, especially small-capacity boilers, are of poor performance. The average operation load is only above 50% of the rated load when operating under 40~70% of the load. When boilers operate under low load, it is difficult to control some operation parameters within the reasonable range, e.g. furnace box temperature, air feed and air leakage factor, and there will be such phenomena as large air leakage, low fire-bed and furnace temperature, obvious decrease of combustion velocity, difficult combustion of fixed carbon in coals and increase of carbon content in slag. Moreover, incomplete combustion loss and flue gas loss increase as the possibility for corrosion of back-end heat recovery surface and soot formation increases due to change in flue gas temperature and velocity, which further reduces the operation efficiency. The operation thermal efficiencies of industrial boilers are generally lower than those specified in technical regulations and standards, about 6-8 percent points lower than the designed efficiency. Main reasons for decrease of operation thermal efficiency of the boiler include unstable operation and combustion, high excess air coefficient, undesirable carbon content in boiler slag, heat loss of flue gas and large loss due to incomplete combustion of fuel.

4. Problem analysis for energy efficiency standards for industrial boilers in China
Since 2010, special equipment inspection organizations in various regions put the energy conservation monitoring of industrial boilers into full swing in accordance with TSG G002-2010 Supervision Regulation on Energy-Saving Technology for Boilers and GB24500-2009 The Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades of Industrial Boilers, and other related documents of Special Equipment Bureau, AQSIQ, and enhanced the infrastructure construction of boiler energy efficiency inspection organization by purchasing all kinds of boiler inspection instruments, meters and equipment and training professional testing personnel with the support from local government. Meanwhile, they performed energy efficiency tests for approved products and boilers in
use, and reviewed the boiler designs in terms of energy conservation as required. At time, the boiler energy conservation standards and management procedures verified conformed to the requirements of China on energy conservation of industrial boilers, which controls the access of industrial boilers with high energy consumption to the market from the source and promotes the improvement of the product design level.

From the current development of the industry and the requirements on energy conservation and emission reduction of industrial boilers in China, the current standards have the following disadvantages:

1) The product structure and performance of industrial boilers are changed and improved to different extents in recent years. The use of clean energy, renewable energy and waste heat accelerate the development of pulverized coal industrial boiler, CWF boiler, gas-fired boiler, biomass boiler, etc., and the energy conservation technologies and products of industrial boiler are further promoted and applied. However, the energy efficiency grade and indexes in GB 24500-2009 cover the existing industrial boilers, so it is necessary to further verify some technical indexes, perfect and supplement the scope of application of the standard when revising the standard.

2) In actual operation, most industrial boilers operate under low load, so such phenomena as idle operation and low average operation load are very common.

3) Technical regulations for boilers and methods and standards for performance tests of industrial boiler are substantially modified. The requirements for test of thermal efficiency of industrial boilers specified in GB 24500-2009 are too simple. The energy efficiency test is to test the continuous operation efficiency of the boiler under rated load. However, the energy efficiency test cannot be performed according to the standard as the thermal load applied by most users cannot satisfy the test requirement, especially for large-capacity hot-water boilers and organic heat carrier boilers.

5. Suggestions for energy efficiency standards for industrial boilers in China

The legislation and measures adopted by development countries for energy conservation of boilers provide reference for the improvement of energy conservation of industrial boilers in China. Currently, the energy conservation ideas of development countries have been shifted from “saving energy to cope with energy crisis” in early 70s of last century to today’s efficiency improvement, pollution reduction, living quality improvement and public relations enhancement. As for standards and regulations regarding energy conservation of industrial boilers in China, it is necessary to determine and modify corresponding energy efficiency indexes and grades by analyzing the energy conservation potential of industrial boilers in consideration of current status and development trends of boiler products. There are some suggestions:

1) Adjust the existing intervals for division of boiler capacity, refine the energy efficiency indexes of boiler products, and increase the allowable values of energy efficiency and energy conservation evaluation values for such products as pulverized coal boilers, CWF boilers, condensing boilers, biomass boilers, electric-heated boilers and waste heat boilers. According to the Implementation Plan for Integrated Improvement of Energy Conservation and Environmental Protection of Coal-fired Boiler, coal-fired boilers with D<10t/h will be knocked out, and standards and regulations for industrial boilers shall be fully applied to revise the energy efficiency indexes for coal-fired boilers with D<10t/h to support the implementation of Integrated Improvement of Energy Conservation and Environmental Protection of Coal-fired Boiler in China.

2) Appropriately improve the energy efficiency of blind coal-fired boilers, oil-fired boilers and gas-fired boilers as per the test results of approved products of existing boilers; properly adjust the energy efficiency of coal-fired boilers proved to be poorly-designed through practice tests so as to encourage boiler manufacturers to independently develop energy conservation coal-fired boilers suitable for actual conditions and fuel features in China.

3) Learn experience from developed countries and introduce the concept of “annual mean fuel availability” as the operation evaluation index in consideration of the actual operation conditions of industrial boilers in China, to gradually shift the focus of improvement of energy efficiency from
product design to the boiler system; research the energy efficiency evaluation indexes under different loads, methods for correction of test results, etc. to maximally reflect the actual operation level of industrial boiler.

4) Currently, the standards for methods of boiler tests have been updated, and it is necessary to revise requirements for energy efficiency tests, and propose the test conditions, methods and requirements, principles for processing of determination data and energy efficiency evaluation, etc. according to the new requirements.

5) Coordinate with relevant technical regulations and product standards for boilers, and propose relevant technical requirements for the achievement of minimum energy efficiency of industrial boilers (including design, type selection, auxiliary equipment, system design, installation, acceptance, fuel management, operation management, equipment maintenance, quality assurance, etc.), so as to satisfy the indexes from design to use and comprehensively improve the energy conservation capacity of industrial boilers in China.

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