Analysis on effects of energy efficiency regulations & standards for industrial boilers in China

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Abstract. 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
Widely applied in factory power, building heating and people’s life, etc., industrial boilers play a quite important role in different sectors of national economy and people’s life of our country. Industrial boilers mainly provide process steam for industrial production and hot water for the public, and are the indispensable consumables of industry and society. 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, Comparative study of domestic and foreign policy and standard documents: to compare the collected policies, regulations, and standards, etc. of international advanced regions (the EU, U.S. and Japan, etc.) on industrial boiler energy efficiency indicators with current domestic standards, to screen out content suitable to China’s national conditions that can be used to perfect Chinese standards.
2. Development of Energy Efficiency Laws, Regulations and Standards

In the U.S. regulation and standard system, besides the U.S. Constitution on the highest level, other five levels from top down are separately laws, ordinances, regulations, standards and guidelines. [1, 2, 3]. U.S. standards on boilers can be divided into six parts. (as shown in Fig. 1).

Fig. 1 U.S. Framework and System of Laws, Regulations and Standards on Boilers

Wherein, the first area concentrates on environmental protection and emissions, and is governed by the Clean Air Act. The EPA, based on the “maximum achievable control technology (MACT)”, has established the Boiler MACT Standards, i.e., National Emissions Standards for Hazardous Air Pollutants, to determine the emission limit levels and enforce legal provisions. The second focus area is energy conservation management. The Energy Policy and Conservation Act requires the DOE to formulate the Minimum Energy Efficiency Standards and test procedures for boilers and revise them when relevant industry standards (such as ASHRAE 90.1 and ANSI/AHRI 1500) are updated. Other four areas focus more on safety, material, certification and test, etc.
U.S. regulations and standards on boiler emissions

2.1. Clean Air Act

The Clean Air Act is the most influential and most important law of the U.S. concerning air pollution, aimed at protecting human health and environment from the harmful emissions in the air. The Clean Air Act, a comprehensive federal law, authorizes EPA to supervise the enforcement of the law, requires EPA to set the minimum national standards for air quality, and specifies the main responsibility of each state to make sure of compliance with such standards.

Started to be made in 1963, the Clean Air Act established a risk-based program during the making in 1970-1990, and set only some standards on hazardous air pollutants. However, with the enhancing of the public’s scientific consciousness on hazardous air pollutants, the Clean Air Act Amendments of 1990 requires EPA to supervise the list of 187 hazardous air pollutants, and further requires EPA to set the technical standards for emission reduction of hazardous air pollutants. The Act specifies that eight years after the technical standards are issued; EPA is required to review those standards to determine whether any residual risk exists and, if yes, revise the standards to address such risk.

2.2. Federal emission regulations

Firstly, EPA, as authorized by the Clean Air Act, classifies the emitted hazardous air pollutants according to the emission source, including:

- Mobile sources, including land, marine and air transportation;
- Stationary sources, including factories, refineries, power plants and buildings;
- Indoor sources, such as building materials and other indoor activities (like cleaning).

EPA shall establish the National Ambient Air Quality Standard (NAAQS) to differentiate different pollutant emission in accordance with the requirements of the Clean Air Act. After several times of revision and update, the latest version of NAAQS has specified the emission limit of benchmark pollutants such as sulfur dioxide, particulate matter, ozone, nitrogen dioxide, carbon monoxide and lead with the following regulations:

| Pollutant            | Average time | Concentration limit |
|----------------------|--------------|--------------------|
| Sulfur dioxide       | Annual average hour | 0.02 ppmv |
|                      | 24h          | 0.14 ppmv          |
|                      | 3h           | 0.5 ppmv           |
|                      | 1h           | 75 ppbv            |
| Particulate matter PM-10 | 24h         | 150μg/m³          |
| Particulate matter PM-2.5 | Annual average hour | 12.0μg/m³ |
|                      | 24h          | 35μg/m³            |
| Ozone                | /            | 0.070 ppm          |
| Nitrogen dioxide     | Annual average hour | 53 ppbv |
|                      | 1h           | 100 ppbv           |
| Carbon monoxide      | 8h           | 9 ppmv             |
|                      | 1h           | 35 ppmv            |
| Lead                 | Average every three months | 0.15μg/m³ |

For implementation of NAAQS, EPA shall adopt the Reasonable Available Control Technology (RACT), Best Available Control Technology (BACT) and Lowest Achievable Emission Rate (LAE) for fixed sources of benchmark pollutant emission, new sources in standard region and new sources in substandard area respectively.

2.3. MACT standard
With rising concerns for environmental protection and public health in the United States, EPA will further divide the pollution emission sources into the following two categories based on the emission intensity and control of pollutants in the United States:

Major pollution sources refer to "any fixed sources or combination of fixed sources" for harmful air pollutants with 10 tons or more annual emissions or combined harmful air pollutants with 25 tons or more annual emissions;

2.4. Emission standard of industrial boilers

MACT can divide boilers and process furnaces into natural gas unit, gas extraction unit, other gas units, light liquid unit, heavy liquid unit and combustion unit for solid fuel (coal and biomass) based on type of units and fuels. It can be divided into less than or equal to 5 MMBtu/h, larger than 5 MMBtu/h and less than 10 MMBtu and larger than or equal to 10 MMBtu/h based on boiler capacity.

EPA has formulated emission restrictions for boiler and process furnace to control five kinds of pollutants, including carbon monoxide (CO), hydrogen chloride (acid gas, HCL), mercury (Hg), particulate matter (PM) and total selected metal (TSM).

EPA has formulated emission restriction for the affected boilers and process furnaces based on heat input of fuels[4,5].

2.5. Boiler adjustment guide

As a core part of the boiler MACT practice program, the owner or operator of main pollution sources and area pollution sources boiler should adjust the boiler according to the fuel source, equipment and boiler based on 1 year, 2 years or 5 years. EPA has issued a boiler adjustment guide to properly guide boiler owners and operators to carry out necessary boiler adjustment. The adjustment will re-establish the air-fuel mixture within the boiler's operating range. Re-adjust the proportion of oxygen and unburned fuel (carbon monoxide is usually indicative) to ensure safe and efficient combustion. Measuring carbon monoxide (CO) concentration to ensure that the burner is working properly. The main goal of boiler regulation is to improve the combustion efficiency of boiler.

3. Energy efficiency regulation and standard of American boiler

The United States attaches great importance to the construction of the legal system in energy management, and pays more attention to strengthening energy conservation management by legal means. The United States has promulgated the Energy Policy and Conservation Act (EPCA) since 1975, the core is the energy security, energy conservation and improving energy efficiency. According to the EPCA, the US Federal energy efficiency standards need to meet the level set in the industry standard, namely the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) standard 90.1, the US Department of Energy (DOE) must establish energy efficiency standards to meet the level specified in ASHRAE standard 90.1. Once ASHRAE modifies the energy efficiency level in standard 90.1, EPCA requires DOE to modify existing federal energy conservation standards. DOE must adopt revised standards with new ASHRAE energy efficiency levels, or if such standards are technically feasible and economically reasonable, a more stringent level should be established.

3.1. DOE boiler energy conservation standards

On November 19, 2007, the US Department of Energy issued the Energy Conservation Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers, (10 CFR Part 430), where the energy efficiency indicators for the boiler are based on Annual Fuel Utilization Efficiency (AFUE), AFUE), the specific indicators are shown in Table 2.
Table 2. Standard Levels for Furnaces and Boilers

| Product class                     | AFUE* (%) |
|----------------------------------|-----------|
| Non-weatherized gas furnaces     | 80        |
| Weatherized gas furnaces         | 81        |
| Mobile home gas furnaces         | 80        |
| Oil-fired furnaces               | 82        |
| Gas boilers                      | 82        |
| Oil-fired boilers                | 83        |

*AFUE = annual fuel utilization efficiency.

DOE issued a rule in 2009 to revise the energy efficiency standards of commercial packaged boilers in order to conform to the latest ASHRAE standard (ASHRAE standard 90.1-2007). The current standards of the revised commercial packaged boilers cover gas and fueled packaged boilers that product low-pressure steam, as well as hot water boilers for building heating or air conditioning and water supply but not in accordance with the definition of "hot water supply boilers", the Capacity of those boiler is 300,000Btu / h or higher. In general, the current minimum efficiency standard for commercial packaged boilers is 77% -84%, depending on fuel type, equipment and boiler capacity.

DOE commercial packaged boiler energy efficiency standard will be revised in 2016, the new standard recommends increase the minimum efficiency level to 81-88%. Currently, the DOE is soliciting public opinion on the proposed rules. When the standard is finalized, manufacturers and distributors can take measures to achieve new efficiency within three years after the final rule is announced.
| Type of equipment | Subclass | Scale (input) | Level of energy efficiency: Effective date: March 2, 2012 | Proposed level of energy efficiency: March 24, 2016 | Date of compliance |
|-------------------|----------|---------------|-----------------------------------------------------------|------------------------------------------------------|-------------------|
| Steam packaged boiler | Gas      | >300,000 Btu/h and ≤2,500,000 Btu/h | 80.0% ET | 85.0% ET | 3 years after the final rules are issued |
| Steam packaged boiler | Gas      | >2,500,000 Btu/h and ≤10,000,000 Btu/h | 82.0% Ec | 85.0% Ec | 3 years after the final rules are issued |
| Steam packaged boiler | Gas      | > 10,000,000 Btu/h | 82.0% Ec | 82.0% Ec | March 2, 2012 |
| Steam packaged boiler | Oil      | >300,000 Btu/h and ≤2,500,000 Btu/h | 82.0% ET | 87.0% ET | 3 years after the final rules are issued |
| Steam packaged boiler | Oil      | >2,500,000 Btu/h and ≤10,000,000 Btu/h | 84.0% ET | 88.0% ET | 3 years after the final rules are issued |
| Steam packaged boiler | Oil      | > 10,000,000 Btu/h | 84.0% Ec | 84.0% Ec | March 2, 2012 |
| Commercial steam packaged boiler | Gas—all except for natural ventilation | >300,000 Btu/h and ≤2,500,000 Btu/h | 79.0% ET | 81.0% ET | 3 years after the final rules are issued |
| Commercial steam packaged boiler | Gas—all except for natural ventilation | >2,500,000 Btu/h and ≤10,000,000 Btu/h | 79.0% ET | 82.0% ET | 3 years after the final rules are issued |
| Commercial steam packaged boiler | Gas—natural ventilation* | > 10,000,000 Btu/h | 77.0% ET | 79.0% ET | March 2, 2012 |
| Commercial steam packaged boiler | Oil      | >300,000 Btu/h and ≤2,500,000 Btu/h | 81.0% ET | 84.0% ET | 3 years after the final rules are issued |
| Commercial steam packaged boiler | Oil      | >2,500,000 Btu/h and ≤10,000,000 Btu/h | 81.0% ET | 85.0% ET | 3 years after the final rules are issued |
| Commercial steam packaged boiler | Oil      | > 10,000,000 Btu/h | 81.0% ET | 81.0% ET | March 2, 2012 |

Note: ET: thermal efficiency; Ec: combustion efficiency.
* Prior to March 2, 2022, the minimum level of thermal efficiency of a large-scale oil-commercial steam packaged boiler with natural ventilation is 77% and complies with the energy conservation standard of federal commercial packaged boilers.
3.2. Energy Star
Energy Star is an energy conservation project for consumer products jointly carried out by United States Department of Energy and United States Environmental Protection Agency under the leadership of the American government. The Energy Star program was started by United States Environmental Protection Agency (EPA) and United States Department of Energy (DOE) in 1992, with the aim to lower energy consumption and to reduce greenhouse gas emission [6].

The rating of boilers in the Energy Star program is based on the Annual Fuel Utilization Efficiency (AFUE) of boilers, and in 2015, the rating of AFUE of the Energy Star program is 87% and above of AFUE of oil fired boilers and 90% and above of AFUE of gas fired boilers.

| Fuel Type | AFUE |
|-----------|------|
| Gas       | 90%  |
| Oil       | 87%  |

It shall be noted that Energy Star is a voluntary labeling system, but the federal government will preferentially procure the products passing Energy Star, and the National Energy Conservation Policy Act also specifies that all public utilities (e.g. supply of water, electricity and gas) must implement economic incentive programs (e.g. cash subsidy) in the form of capital, in kind or in the form of service, etc. to encourage the promotion and application of products certified by Energy Star, and the United States federal government, all state governments and public utilities have carried out the cash subsidy program of products certified by "Energy Star" respectively. A majority of manufacturers find that if their products pass the certification of Energy Star and are provided with the Energy Start mark, the business benefits will be brought for the sales of products, so an increasing number of users also can select high-efficiency products through subsidy policies.

4. Thinking of Energy Efficiency Standards of American
The energy conservation and emission reduction policies of American industrial boilers are formulated by the United States federal government, state governments and local governments, stipulating the specific work of energy conservation and emission reduction management of boilers. For the specific technical indicators, the standards of technical institutions or organizations for standardization will be quoted and transformed into the regulations to be compulsively executed. Therefore, regulations are closely combined with standards and gradually detailed from top to bottom according to different contents of energy conservation and environmental protection concerned, the laws embody the basic regulations from top to bottom, the regulations clearly specify the supervisions requirements and management measures, and the standards stipulate a variety of technical details, methods and modes.

The energy efficiency standards of the United States are classified into mandatory and voluntary standards. After careful consideration, the DOE and the EPA take full account of actual operating conditions and improve the cost of energy efficiency during the formulation of mandatory energy efficiency standards so as to avoid the phenomenon of energy conservation but not cost saving; for voluntary indicators, if the Energy Star program is used to set up a national benchmark, the method of certification and publicity will be adopted to guide manufacturing enterprises to engage in the development and research of products with the energy-costing technology, the policies of subsidy or tax abatement will be used to guide consumers to purchase high-efficiency products and the market mechanism will be continuously improved, so that the governments, manufacturing enterprises and users can benefit from energy conservation and emission reduction efforts. Consequently, a virtuous circle that the benchmarking level and operation of boiler energy efficiency are continuously increased and the standard requirements are continuously improved will be established.

For the purpose of setting the energy efficiency and environmental protection indicators, the United States mainly embodies the principle of conformity of energy conservation and environmental protection, and CO, which mainly influences the boiler energy efficiency, is listed in the regulation of
emission limitations; meanwhile, in accordance with the MACT standard, the top 12% of overall energy efficiency is used as the benchmark, reflecting the thinking of combination of energy conservation and environmental protection of boilers. In addition, for the energy efficiency indicators, the thermal efficiency of boiler is not highlighted, and the minimum energy efficiency standard and Energy Star of the DOE are reflected in the concept of Annual Fuel Utilization Efficiency (AFUE) of enterprises or industries and are more close to the operation of equipment and production of enterprises, so as to reflect the level of energy efficiency in a more authentic and scientific manner.

The United States focuses on the concept of utilization of system energy, and especially the assessment of operating conditions of boilers is mainly based on the system energy assessment and the ratio of manual energy input and heat output for the purpose of assessing the operating conditions of system, identifying the problem of system operation, recognizing the potential opportunity for energy conservation in the whole system or enterprises, applying the analysis software developed by the DOE, e.g. SSAT, SSMT and decision tree, to analyze and realize the ratio of funds input and output of energy-saving opportunities and finally selecting the optimum scheme to realize the maximization of energy benefits, so as to promote an increase in the level in a scientific way.

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