

Hazard assessment of hot water boiler at thermal power plant

Vladimir Gordeev¹, Elina Nasyrova¹, Alexey Elizaryev¹, Alsu Fazylova^{1}, and Elvira Kamaeva*

¹Ufa University of Science and Technology, 32, Z. Validi street, Ufa, 450076, Republic of Bashkortostan, Russia

Abstract. Our world and every person require a huge amount of energy, both electric and thermal, which are produced mainly at various types of power plants, but mostly on thermal. During the production of electricity and heat at the thermal power plants different potential hazards are occurring: chemical, environmental, fire or explosion. In accordance with the identified hazards on thermal power plants, possible six emergency situation scenarios are suggested. The failure tree method was used for determining the potential danger of a hot water boiler being one of the elements of thermal power plant. Given the conditional probabilities of events, it is obtained that the failure of the hot water boiler is possible. For reducing the probability of failure and improving the hot water boiler safety – safety barriers (functional and symbolic) are proposed. After the safety barriers are inserted, the probability of a hot water boiler failure in our case is almost incredible. Many people live near thermal power plants, which may have a potential risk of harm to their health. An approach for determining the potential risk indicator of the health harm (R) near thermal power plants is proposed. It provides the division of risk levels into four classes: extremely high degree of potential hazard – $R > 0.1$; high degree of potential hazard – $0.1 > R > 0.001$; average degree of potential hazard – $10^{-3} > R > 10^{-5}$; low degree of potential hazard – $R > 10^{-5}$.

1 Introduction

The modern world requires a huge amount of energy, both electric and thermal, which are produced mainly at various types of power plants. In this regard, heat power engineering facility play a significant role in the production of energy for the population. For example, thermal power plants are designed for producing electricity for the population; they are also a thermal energy source (steam and hot water) in centralized heating and hot water supply systems of residential and industrial objects.

One of the life safety axioms states that any activity is potentially dangerous. This axiom assumes that all production processes, except for positive properties and results, have the ability to generate hazards. The problem of potential hazards occurring during the

* Corresponding author: alsy-fazylova2013@yandex.ru

production of electricity and heat at the thermal power plant is very relevant at the moment and is being investigated by many researchers.

For example, Shrivastava and Patel [1] had analysed physical, chemical, biological and environmental hazards of thermal power plants and the event sequences leading to those hazards. Other authors [2] used Interpretive Structural Modelling (ISM) for assessing the interrelationships between hazards. Mainul Bari et. al [3] identified and prioritised the operational hazards of the power plants through using a hybrid multi-criteria decision-making (MCDM) approach in a fuzzy environment.

The environmental hazard of coal based thermal power plants such as fly ash is considered in the works [4-7]. Occupational hazard as an inherent danger in the operation of the thermal power plants is considered by authors Yang et. al [8], Hole et. al [9] and Diao [10]. Thermal power plants are the source of fire and explosion. For example, in work [11] authors estimated this dangers by using the Dow fire and explosion index. Other authors [12] proposed effective strategies for fire prevention by the fire risk results in the control room of a power plant.

After analyzing the works by potential hazards of thermal power plants, it was found that thermal power plants are characterized by various types of hazards. Each of them is capable of harming production and the environment. It is necessary to take into account the potential danger of each element on thermal power plants, since in accident at the object the consequences may be of a different nature. The purpose of this work is to assess the potential danger of hot water boilers, as an element of the thermal power plants.

2 Materials and methods

Particularly fire-hazardous elements at a thermal power plant based on natural gas and using fuel oil as a backup fuel are: fuel oil tank and pipeline; cable compartments in machine room; oil turbine systems; hydrogen-cooled turbo generators; oil-filled transformers; gas distribution points and pipelines; steam/water boiler (fig. 1).

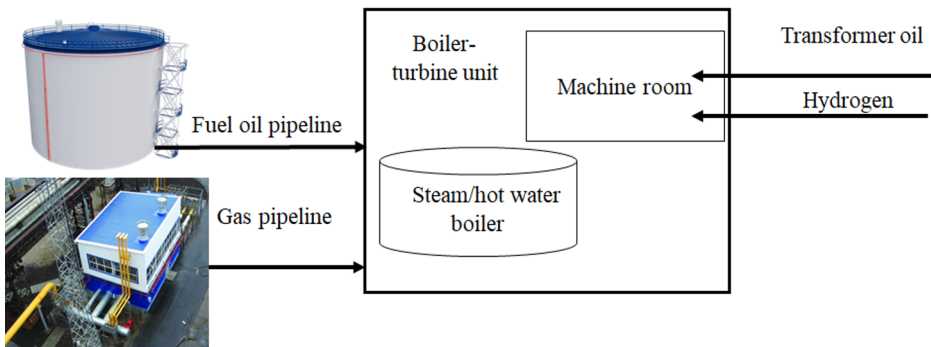


Fig. 1. Fire and explosion elements of thermal power plants.

At electric power facilities, industrial boilers are divided into hot water and steam boilers according to the heat carrier («output product»). Steam boilers are designed for steam production and are divided by their purpose into:

- energy boilers that produce steam used in steam turbines to generate electrical energy. Similar boilers are used at thermal power plants in conjunction with turbo generators – turbo unit;

– industrial boilers that generate steam for technological needs. Industrial boilers produce saturated steam, and energy boilers produce superheated steam.

The hot water boiler is designed for heating water under pressure. Boiling of water in the boiler is not allowed if: its pressure at all points is higher than the saturation pressure at the temperature reached there. Hot water boilers are mainly used for heat supply at district boiler houses and thermal power plants.

The failure tree method was used for determining the potential danger of a hot water boiler at thermal power plant. This is a graphical representation of the logical connections between the events – accidents (emergencies) and the events that initiate them.

For reducing of an emergency probability, that is, a physical explosion of a hot water boiler, the method of safety barriers was used.

3 Results and discussion

In accordance with the identified hazards on thermal power plants, possible emergency situation scenarios are suggested.

Scenario 1: an accident on an internal gas pipeline.

Scenario 1-1: gas emission from the destroyed gas pipeline → failure of the emergency gas shut-off system → ignition and explosion of the gas-air mixture.

Scenario 1-2: gas emission from the destroyed gas pipeline → failure of the emergency gas shut-off system → ignition and explosion of the gas-air mixture → activation of easy-to-throw structures (if available).

Scenario 1-3: gas leak from gas pipeline → operation of the emergency gas shut-off system → ventilation of the room.

Scenario 1-4: gas leak from gas pipeline → failure of the emergency gas shut-off system → ignition and explosion of the gas-air mixture.

Scenario 1-5: gas leak from gas pipeline → failure of the emergency gas shut-off system → ignition and explosion of the gas-air mixture → activation of easy-to-throw structures (if available).

Scenario 2: an accident on an external gas pipeline.

Scenario 2-1: gas emission from the destroyed gas pipeline → failure of the emergency gas shut-off system → formation of a gas-air mixture and explosion of a gas-air mixture → stopping boilers.

Scenario 2-2: gas emission from the destroyed gas pipeline → operation of the emergency gas shut-off system → formation of a gas-air mixture and its dispersion → stopping boilers.

Scenario 2-3: gas leak from gas pipeline → failure of the emergency gas shut-off system → formation of a gas-air mixture and explosion of a gas-air mixture → stopping boilers.

Scenario 2-4: gas leak from gas pipeline → operation of the emergency gas shut-off system → stopping boilers.

Scenario 3: accident on transformer oil pipeline.

Scenario 3-1: depressurization of the oil pipeline → transformer oil spill inside the room → evaporation and formation of a vapor-air cloud → ignition (if there is an ignition source) → spill fire.

Scenario 4: accident on the hydrogen pipeline.

Scenario 4-1: hydrogen emission from the destroyed pipeline → failure of the emergency gas shut-off system → ignition and explosion of the gas-air mixture.

Scenario 4-2: hydrogen emission from the destroyed pipeline → operation of the emergency gas shut-off system → ventilation of the room.

Scenario 4-3: hydrogen leak from gas pipeline → failure of the emergency gas shut-off system → ventilation of the room.

Scenario 4-4: hydrogen leak from gas pipeline → failure of the emergency gas shut-off system → ignition and explosion of the gas-air mixture.

Scenario 5: accident on the boiler (steam or hot water).

Scenario 5-1: failure of boiler components → steam accumulation inside the boiler → boiler explosion.

Scenario 6: accident on a fuel oil pipeline.

Scenario 6-1: depressurization of the fuel oil tank → fuel oil spill in embankment → evaporation → formation of a vapor-air cloud → ignition in the presence of an ignition source → spill fire.

Scenario 6-2: depressurization of the fuel oil tank → fuel oil spill in embankment → absorption of fuel oil by soil → environmental pollution.

Scenario 6-3: quasi-instantaneous destruction of the fuel oil tank → overflow of fuel oil through embankment and free distribution of fuel oil → evaporation → formation of a vapor-air cloud → ignition in the presence of an ignition source → spill fire.

Scenario 6-4: quasi-instantaneous destruction of the fuel oil tank → overflow of fuel oil through embankment and free distribution of fuel oil → absorption of fuel oil by soil → environmental pollution.

The above scenarios show that a fire and explosion are possible at the thermal power plants.

During the hot water boiler operation the most frequent causes of failures are: operation with disabled protection systems, incorrect installation of the operating mode, boiler operation with pipe defects, use of low-quality water, operation at a pressure that does not meet the manufacturer's recommendations and others. Based on hot water boiler operating principles and possible accidents causes, a failure tree is compiled (fig. 2).

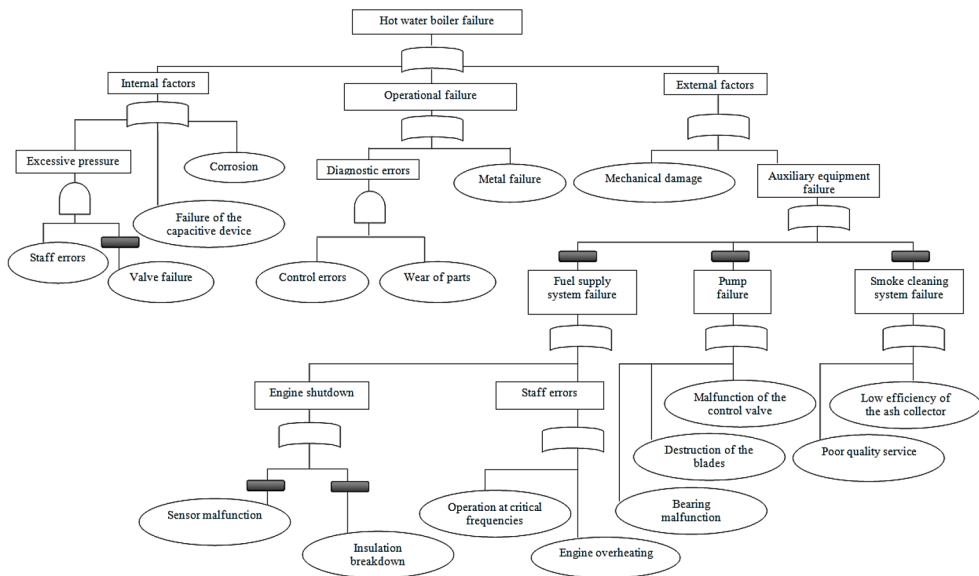


Fig. 2. Hot water boiler failure tree.

Given the conditional probabilities of events, it is obtained that the failure of the hot water boiler is possible (10^{-4} - 10^{-2}).

If the originally designed system protective mechanisms are not able to prevent negative effects, then additional measures are introduced, which are called safety barriers. Barriers

are understood as physical or non-physical methods and means designed to prevent, control or mitigate undesirable events or accidents. These barriers can represent both certain simple human actions and a large independent system. Barriers classify into: material, functional, symbolic – signals perceived by a person, immaterial (for example, rules, principles).

Safety barriers are proposed for the constructed hot water boiler failure tree (they are highlighted on fig.1 as filled rectangles):

– functional: replacement of cyclones with hollow scrubbers, installation of additional gas-blowing equipment, installation of more modern sounders for the gas-blowing installation, replacement of outdated sensors with modern ones, high-quality insulation of engine electric cables, replacement of the relief valve with a more sensitive one.

Symbolic: increasing the frequency of maintenance and inspections of the feed pump.

After the safety barriers are inserted, the probability of a hot water boiler failure in our case is almost incredible ($<10^{-4}$).

A large number of industrial facilities, in particular thermal power plants, are located within the city. Many people live near these objects, which may have a potential risk of harm to their health. Each of the considered thermal power plant hazards can have an impact on the population by: environmental pollution due to emissions and discharges, chemical exposure in the chemical accident at the object, fire or explosion.

The potential risk indicator of the health harm (R) can be represented as:

$$R = p \cdot U \cdot M, \quad (1)$$

where p – indicator of the weighted average violations frequency;

U – potential harm indicator to human health;

M – an indicator of the population under the influence of an object, i.e. it may be under the influence of one thermal power plant hazards: chemical, environmental, fire or explosion.

In accordance with Russian regulatory documents for objects of production, transmission and distribution of electricity, gas, steam and hot water: $U=0,0194$; $p=5,59$. The indicator M is variable, so this value may vary. In this work, we proposed to determine M for thermal power plants through the population density and the zone of potential danger.

Let's return to our hot water boiler and estimate potential risk indicator of the health harm.

In accordance with scenario 5 the potential hazard of hot water boiler is explosion. A physical explosion is a process of rapid physical transformation, accompanied by the transition of potential energy into mechanical work. The most significant sign of an explosion is a sharp pressure jump in the environment surrounding the explosion site. This is the direct cause of the explosion destructive effect. Hot water boiler explosion is caused by the rapid transition of superheated water into a vaporous state. The damaging factors of a physical explosion are an air shock wave and a fragmentation effect. After calculating the excess pressure of the air shock wave, the impact area is determined. Accordingly M is calculated as multiplication of population density in the city to impact area.

To classify objects, including thermal power plants, according to the potential risk indicator of the health harm, a scale is used, that provides the division of risk levels into four classes:

- 1) extremely high degree of potential hazard (I hazard class) – $R>0.1$;
- 2) high degree of potential hazard (II hazard class) – $0.1>R>0.001$;
- 3) average degree of potential hazard (III hazard class) – $10^{-3}>R>10^{-5}$;
- 4) low degree of potential hazard (IV hazard class) – $R>10^{-5}$.

4 Conclusion

Thus, the paper considers the main types of potential hazards on thermal power plants. Taking into account the fire and explosion hazard of the main elements on thermal power plants, scenarios of emergency situations are proposed. One of the possible scenarios is a physical explosion of a hot water boiler. A tree of hot water boiler failures has been compiled, which made it possible to analyze failures and place safety barriers. The paper also suggests an approach for determining the potential risk indicator of the health harm.

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