ECONOMIZERS AND COLD-END CORROSION

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ABSTRACT

Energy recovery today is in a very critical position in terms of maintaining the competitiveness by reducing costs and sustainability of environmental awareness by reducing emissions. Economizers have an important role in boiler applications which consume the most of the fossil energy in recent years. What is important here is to determine the correct method by optimizing energy recovery and investment costs. The most important parameter limiting the heat recovery in economizer applications is cold-end corrosion on the smoke side. In this study, economizers and cold-end corrosion will be examined in general and basic information will be given about various methods to increase energy recovery in economizers.

Keywords: Energy recovery, economizers, cold-end corrosion

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INTRODUCTION

Economizer by definition; it means a heat exchanger that recovers this low temperature heat by reducing the flue gas temperature of any heat boiler and saves extra fuel. Although it is used in many other types of boilers such as hot water boilers and hot oil boilers, the main area is steam boilers. Today, it is one of the indispensable units of especially large-capacity steam boilers. Although it varies according to the air excess coefficient and fuel type, approximately 21°C decrease in flue gas temperature means an average 1% increase in total boiler efficiency. [1,2] This value also indicates the reduction in fuel consumption. Since the flue gas flow rate is higher in cogeneration applications (especially gas turbine applications) where the air excess coefficient is high, the temperature drop value required for a 1% efficiency increase is less. Approximate amount of savings according to normal excess air coefficients and fuel types for boiler applications can be seen in Figure 1.

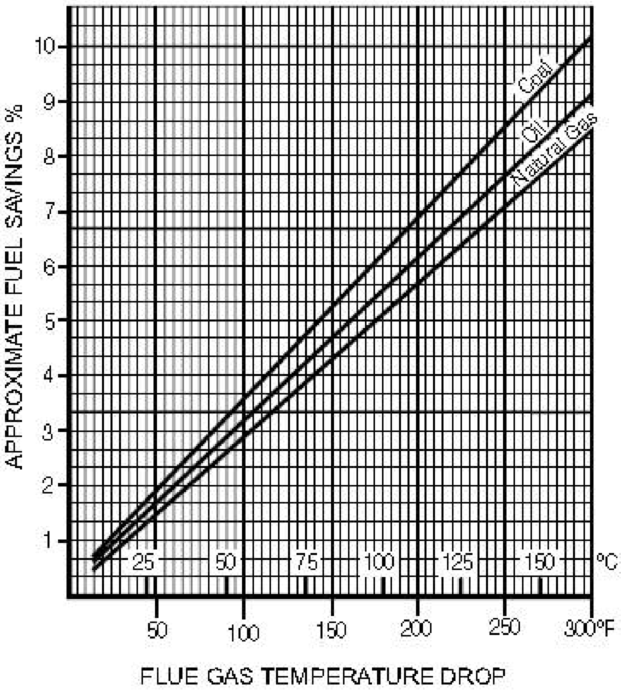

Figure 1. Efficiency Increase in Boiler Due to Drop in Flue Gas Temperature [1]

The values seen in Figure 1 are the values that can be obtained if the water vapor in the flue gas does not condense. However, especially in natural gas applications, there is around 10% water vapor in the flue gas. If the necessary precautions are taken and the flue gas can be cooled down to, for example, 40-50 ºC, the water vapor in it will condense, albeit partially, and the total boiler efficiency can be easily increased above 100% according to the lower heating value. The condensation temperature depends on the amount of water vapor in the flue gas, and as the amount of water vapor increases, the condensation temperature also increases. For instance, while the condensation temperature in the flue gas of a natural gas boiler with a high water vapor ratio is around 56 °C, the condensation temperature in the exhaust of a gas turbine with a low water vapor ratio is around 40 °C.

While determining the condensation temperature, the molar percentage of the water vapor is calculated, the partial pressure of the water vapor in the total gas pressure is found from there, and the saturation temperature corresponding to this partial pressure is determined as the condensation temperature. Another important issue in condensing economizers is the pressure drop on the gas side. If necessary, evacuating the flue gas with an induced-draft fan is common in most applications. A condensing economizer application can be seen in Figure 2.

Because the evaporator part of the steam boiler is a constant temperature heat exchanger, it is thermodynamically impossible to reduce the flue gas temperature below the saturated steam temperature. The closer the gas outlet temperature approaches the evaporator saturation temperature, the greater the evaporator thermal surface logarithmically increases in the same direction. In addition, since the water side temperature average in the economizer is lower, less thermal surface is required compared to the evaporator to gain the same heat. The degree to which the flue gas temperature approaches the evaporator operating temperature is defined as *the Pinch Temperature* in the literature.

Depending on the design and operating conditions, this value can be between 20 and 50 °C in boilers with burners, while it varies between 10 and 25 °C in waste heat boilers. While low *Pinch Temperature* provides high efficiency, it also means high investment cost and high flue gas resistance. For this reason, especially in waste heat boilers, the system is designed by making optimization studies with all these parameters.

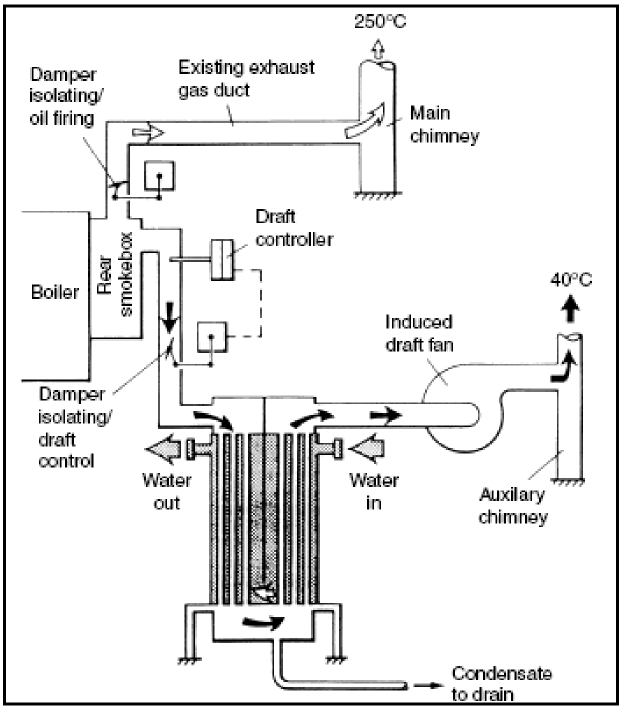

Figure 2. An Example of Condensing Economizer Application [1]

Another heat recovery device used similarly in industrial boilers is the air heater. These devices can also be called as recuperators in the market, are not as attractive as economizers for industrial applications, for reasons that will be mentioned below.

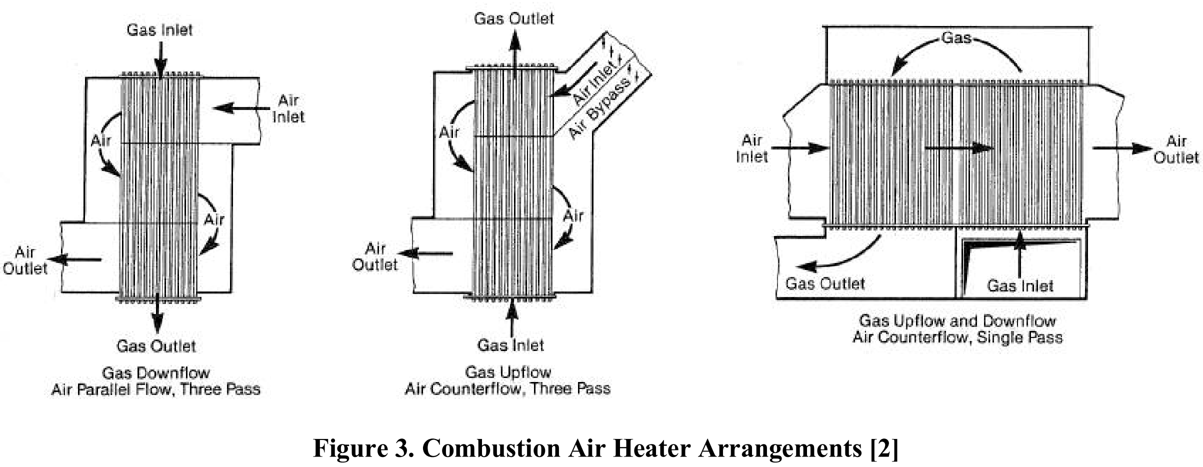

Figure 3. Combustion Air Heater Arrangements [2]

Comparison of Air Heaters and Economizers

Although air heaters are not as common as economizers, they are especially preferred to improve combustion in pulverized coal-fired power boilers. Apart from this, they are also widely used in industrial applications, especially for heating the combustion air of hot oil boilers. The disadvantages of economizers can be summarized as follows;

- Since the heat transfer coefficient from gas to air is much lower than the heat transfer coefficient from gas to water, they generally require a larger thermal surface. Therefore, their initial investment costs are higher and they require a larger settlement volume.
- They cause high pressure losses on the gas side and especially on the air side as they have more thermal surfaces. In addition, as the oxygen density of the air decreases, a higher volume flow requirement arises. These increase the initial investment and operating costs by increasing the burner motor power.
- Special tube materials may be required at high flue gas and air temperatures due to poor heat transfer. This increases the investment cost.
- On average, every 100 ºC increase in combustion air temperature causes an approximately 50 ºC increase in flame temperature. This increases NOx formation. NOx derivatives seriously threaten human health with effects such as nitric acid rain, unwanted ozone formation and particle formation.
- Since the air and gas side heat transfer coefficients are close to each other in air heaters, it is not possible to achieve compactness by using finned surfaces as in economizers.

Types and General Structures of Economizers

Economizers are produced in smoke tube and water tube types, and water tube constructions are more commonly used. In smoke tube economizers, the flue gas flows through the tube, while the water circulates outside the tube at a much slower rate. Therefore, the heat transfer coefficients are low. Therefore, higher heat transfer surface is required for the same capacity. The volume they cover is high, so their investment costs are high.

Since the water volumes are too large, they cause heat loss, especially in systems that stop too much. A certain period of time passes from the cold start to the regime, since this period is much longer than the water tube constructions, the condensation time on the tube walls is also longer.

As a result, tube punctures occur earlier. However, nowadays they are partially preferred especially in coal and similar fuels with high soot potential. In this study, water tube economizers will be examined due to their superiority.

In water tube economizers, the heated water flows through the tube, and the gas, which heats it, flows outside the tube. The water velocity in the tube can be kept high by increasing the number of passes, so a good heat transfer coefficient can be obtained. The result is a very compact and low-cost design. The desired heat transfer surface can be obtained by increasing the number of passes on the gas side. Figure 4 shows a gas side single pass water tube economizer.

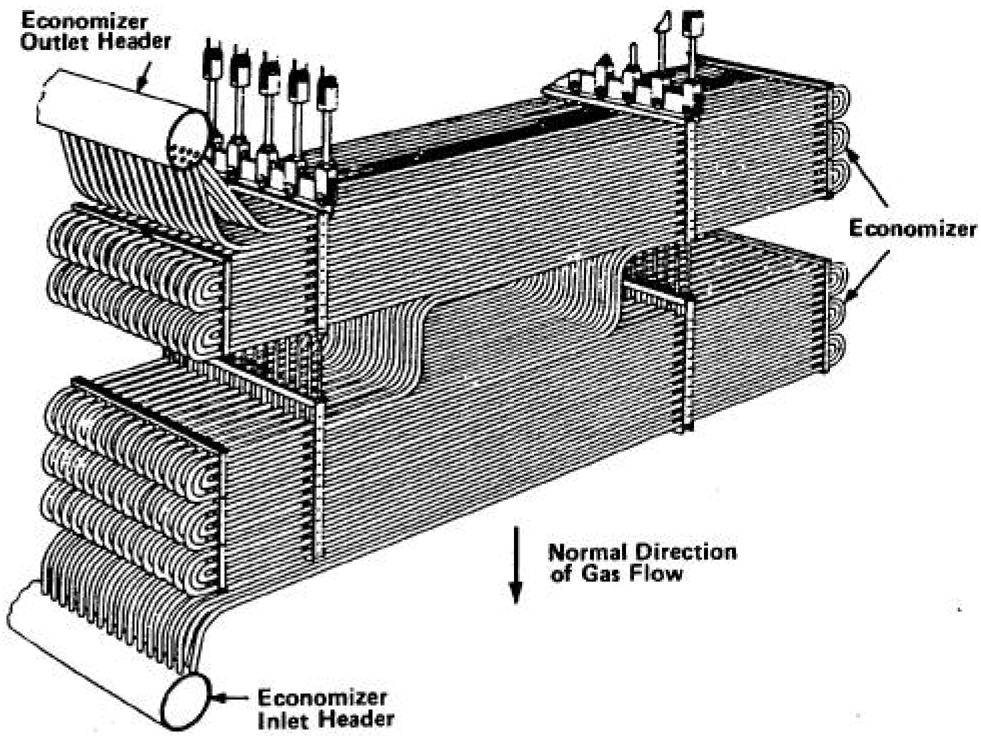

Figure 4. Water Tube Economizer Designed for a Power Boiler [6]

Tubes to be used for heating surfaces can be selected with diameters between 1" and 2", with or without seams. The important thing is to use the right material according to the application conditions. The piping arrangement can be square or deflected. The baffled arrangement gives a better heat transfer coefficient, while the gas side pressure drop is greater. However, it is generally the preferred method for clean fuels such as natural gas. In applications with high particle load, more square arrangement is preferred due to the ease of cleaning.

The speed on the water side depends on the acceptable pressure drop, but can be selected between 1 - 2.5 m/s. [10] Velocities on the gas side depend on the pressure drop and, more importantly, on the corrosive nature of the flue gas, it can vary between 10 – 20 m/s. [2] While performing the design, factors such as thermal expansions, vibrations and interoperability should be considered, as well as pressure drop and heat transfer optimization. The opposite direction of water and gas flows is the most suitable arrangement for the efficiency of heat transfer. Moreover, arranging the water flow from the bottom up helps to reduce the dead spots created by possible steam pockets. Economizer thermal surfaces may consist of straight tubes or finned tubes. It is the gas side that mainly determines the overall heat transfer coefficient. In order to reduce this high thermal resistance on the gas side, fins, that is, expanded thermal surface elements are used. Finned tubes provide great advantages especially in clean fuels. The thermal surface can be increased up to ten times for the same tube length. [2] The cost, on the other hand, does not increase proportionally because the fin material and workmanship is generally lower than that of the tube.

The fins are produced in various structures and the most commonly used types are rectangular helical and segmented blades. Segmented fins provide better heat transfer due to their high turbulence, while at the same time, pressure drops are higher. Fin pitches can be reduced to 3 mm for natural gas, while it can be increased to 12-13 mm for Fuel-oil and similar. [6] The fact is that the fins are welded along the contact surface of the tube, although it increases the cost considerably. Thus, a long service life is ensured together with an effective heat transfer.

Economizer tubes generally cool well as they provide an effective heat transfer with water. The tube wall temperature is usually 5-10 $^{\circ}$C higher than the inside water temperature. For this reason, as long as there is no possibility of corrosion, if it is suitable in terms of strength, for example, St 35.8 boiler tube can be used for most applications. Special alloy materials can be selected at very high pressures or in situations where corrosion is likely. Fin materials are determined by calculating the fin tip metal temperature. Here, strength is not important, only the upper use temperature of the material, corrosion resistance if necessary, and cold workability. Usually, St 37 sheet fin material can be used up to a material temperature of 350 $^{\circ}$C. For higher temperatures, ferritic stainless steels such as AISI 409 with good cold forming capabilities can be preferred. In cases where condensation is in question, austenitic stainless steels such as AISI 304L, AISI 316L with good weldability or AISI 316Ti with high acidic resistance can be preferred for both the tube and the fin.

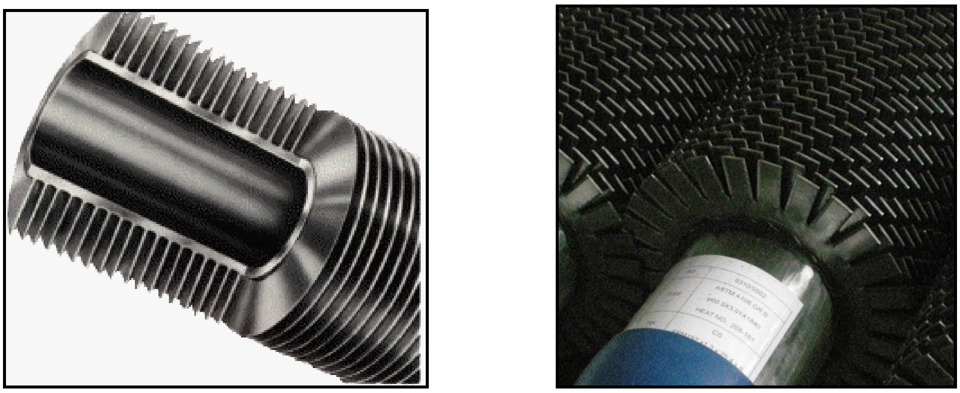

Figure 5. Types of Fins Commonly Used in Economizers

CORROSION

It can generally be defined as the corrosion of the material by reacting with the external fluid (H2O, SO3, NOx, HCl, O2 or acidic fluids formed by CO2). It is one of the most common problems in economizer and similar equipment. In general, it can be grouped as tube inside and outside tube corrosion. In-tube corrosion occurs due to corrosive gases such as O2 and CO2 present in the heated fluid. For this purpose, the feed water is generally degassed at 105 $^{\circ}$C and fed to the boiler. However, in cases where the water temperature is lower, the existing corrosive gases may cause puncture in the economizer tubes. In this study, mainly gas side corrosion will be examined. Corrosion on the gas side can be divided into high temperature and low temperature corrosion.

High Temperature Corrosion

Corrosive sodium and vanadium salts are formed as a result of the burning of heavy fuels, especially FO, and these salts melt at high temperatures and adhere to the tube surfaces. This creates a potential corrosion hazard. In addition, a 1 mm thick layer formed on the flue gas side can reduce the boiler efficiency up to 2%. In order to prevent this, the heating surfaces should be designed to minimize accumulation and care should be taken that the amount of vanadium in the fuel ash does not exceed 100 ppm. [10] Since economizers are not exposed to very high gas temperatures, this problem is not as common as low temperature corrosion.

Low Temperature Corrosion

Flue gas formed as a result of combustion is a mixture of various molecules. As the temperature of this mixture decreases, the gas components in it begin to condense. While there are components that start to condense at very low temperatures (NOx), there are also those that start to condense at very high temperatures. As can be seen in the tables below, the component with the highest condensation temperature is sulfur trioxide (SO_3). For this reason, sulfuric acid corrosion is the most common situation in natural gas and FO burning boilers.

Sulfuric acid corrosion caused by SO_3 occurs when the metal temperature drops below the condensation temperature of SO_3 in the flue gas. It is usually seen in low temperature areas such as economizer, air heater, smoke ducts and chimney. In order to perform a low temperature corrosion analysis, first of all, it is necessary to look at the flue gas analysis and the condensation temperatures of the existing components. The tables below show the condensation temperatures depending on the partial pressures of water and other common corrosive gases. The points to be considered while performing corrosion analysis are summarized as follows;

- Considering the partial pressures of each gas component and the tube metal temperature, it should be determined which gas component will condense.

- During the condensation of this component, the type of corrosive environment will be determined and the materials to be used should be determined or necessary precautions should be taken if condensation is not desired.

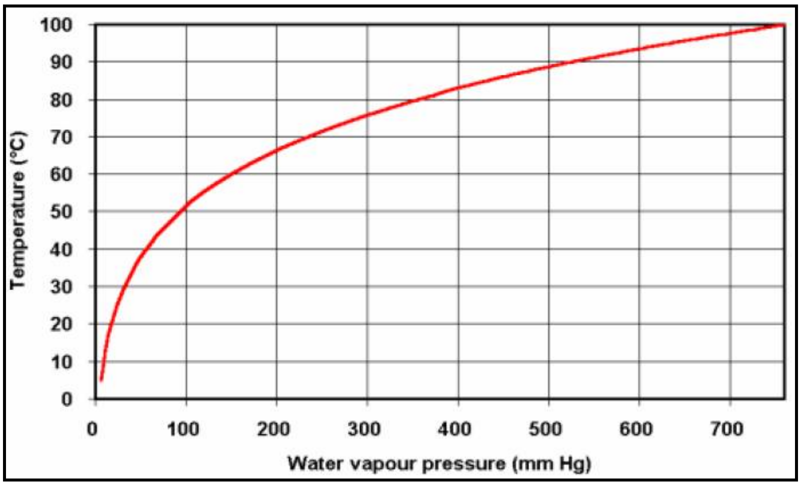

Figure 6. Condensation Temperatures According to Partial Pressure of Water Vapour. [3]

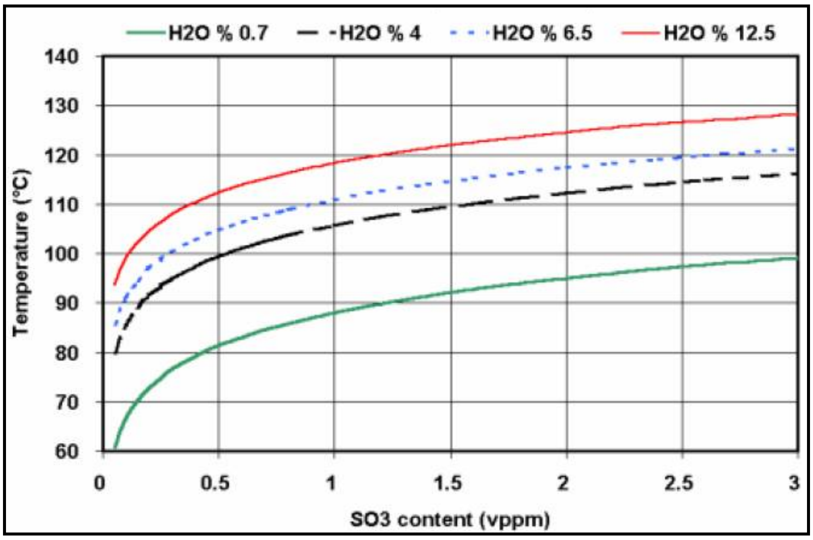

Figure 7. Condensation Temp. by Volume Composition of SO3 & Percent. of Water Vapor in the Gas.[3]

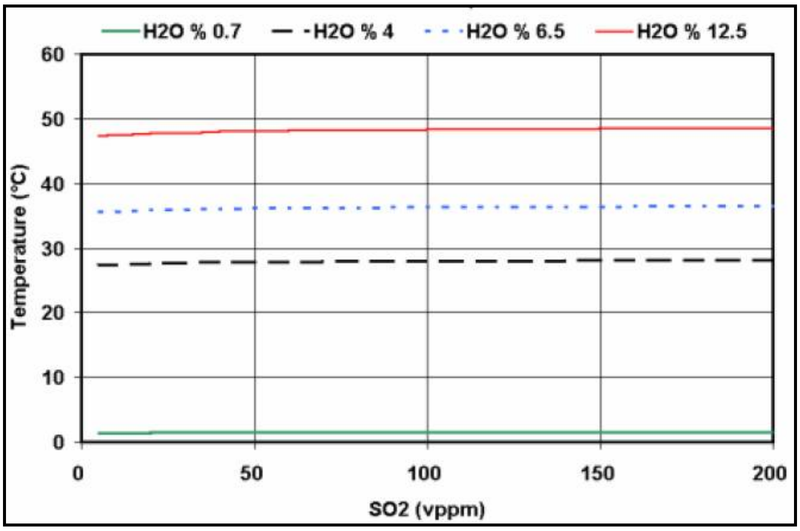

Figure 8. Condensation Temp. by Volume Composition of SO2 and Percent. of Water Vapor. [3]

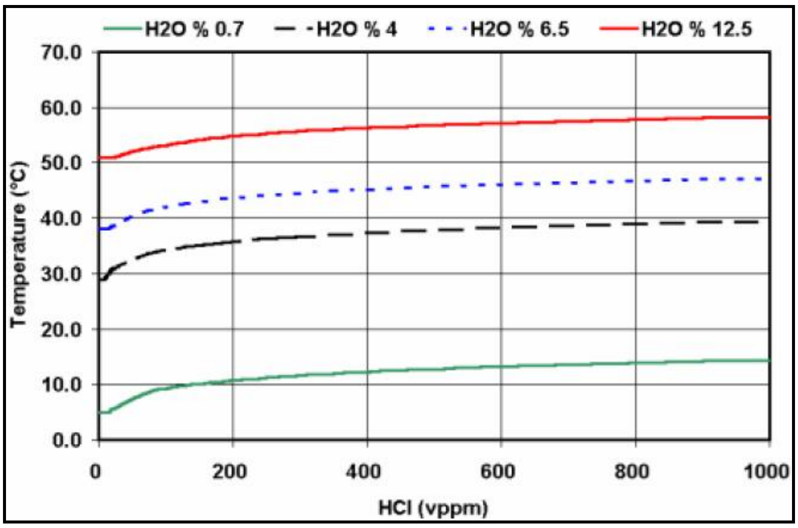

Figure 9. Condensation Temp. by Volumetric Composition of HCl and Percentage of Water Vapor. [3]

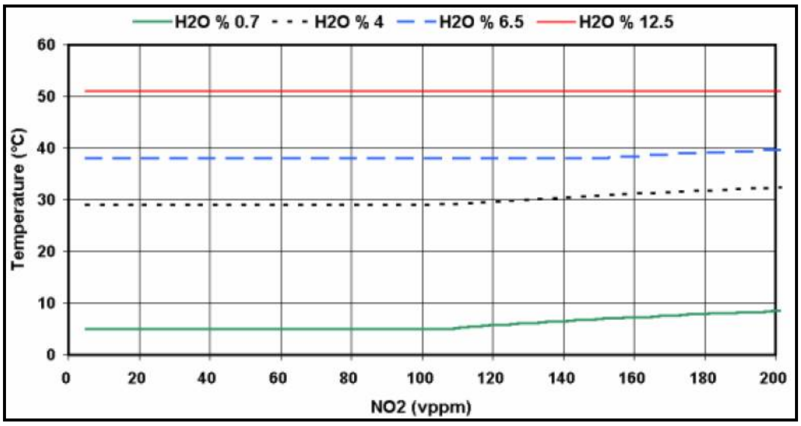

Figure 10. Condensation Temp. by Volumetric Composition of NO2 and Percent. of Water Vapor. [3]

As can be seen from the tables, the most risky component in terms of low temperature corrosion is sulfur trioxide. (SO_3). Basically, the sulfur in the fuel and the oxygen in the combustion air react to form sulfur dioxide. (SO_2)

$$S + O_2 \rightarrow SO_2 \quad (1)$$

A very small part of the SO_2 formed after this reaction reacts with the atomic oxygen in the flame depending on the fuel and air excess coefficient and forms SO_3, which has the highest corrosion potential. (Figure 11)

$$SO_2 + O \rightarrow SO_3 \quad (2)$$

In addition, elements such as Vanadium and Nickel in the fuel increase the SO3 conversion rate by creating a catalytic effect. [7]

$$SO_2 + \frac{1}{2}O_2 + Catalyst \rightarrow SO_3 \quad (3)$$

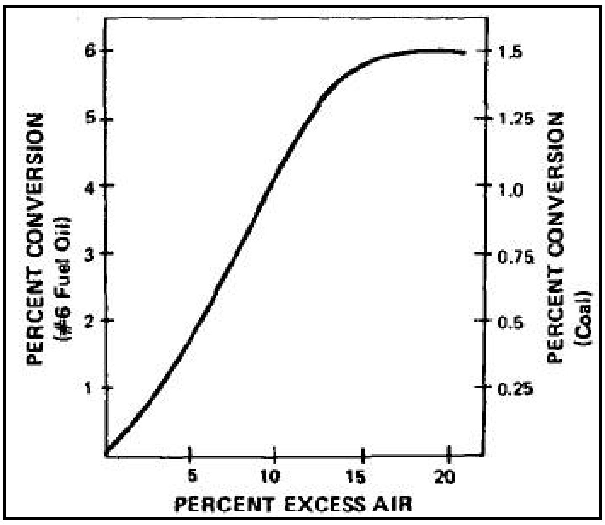

Figure 11. Percent. of Conversion of Sulfur to SO3 by Air Excess Coefficient and Fuel. [4]

An Example of Condensing Temperature Calculation

For FO fuel, the volumetric analysis in the flue gas is assumed as; If H_2O: 10%, SO_2: 0.08% and air excess coefficient is 10%, let's determine the sulfuric acid condensation temperature.

It appears that for 10% excess air and FO fuel, about 4% of the sulfur will be converted to the SO_3 form. Accordingly, the final SO_3 composition is determined as 10-2 x 0.08 x 0.04 = 32 x 10-6 = 32 ppmv. In this case, it can be seen from the table below that the condensation will start at 150 ºC [5]

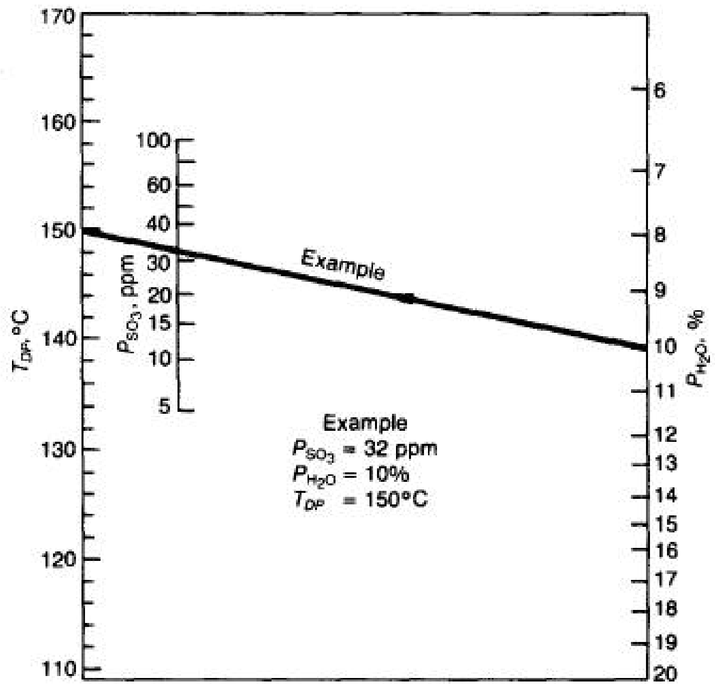

Figure 12. Smoke Gas Condensation Temperatures According to SO3 and H2O Compositions. [5]

The required minimum design metal temperatures for FO and coal can be taken from Figure 13. Accordingly, with a rough approach, the sulfur content of the coal should not exceed 2% and the FO should not exceed 2.5% for the 100 ºC feed water intake. If it does, action should be taken. [6]

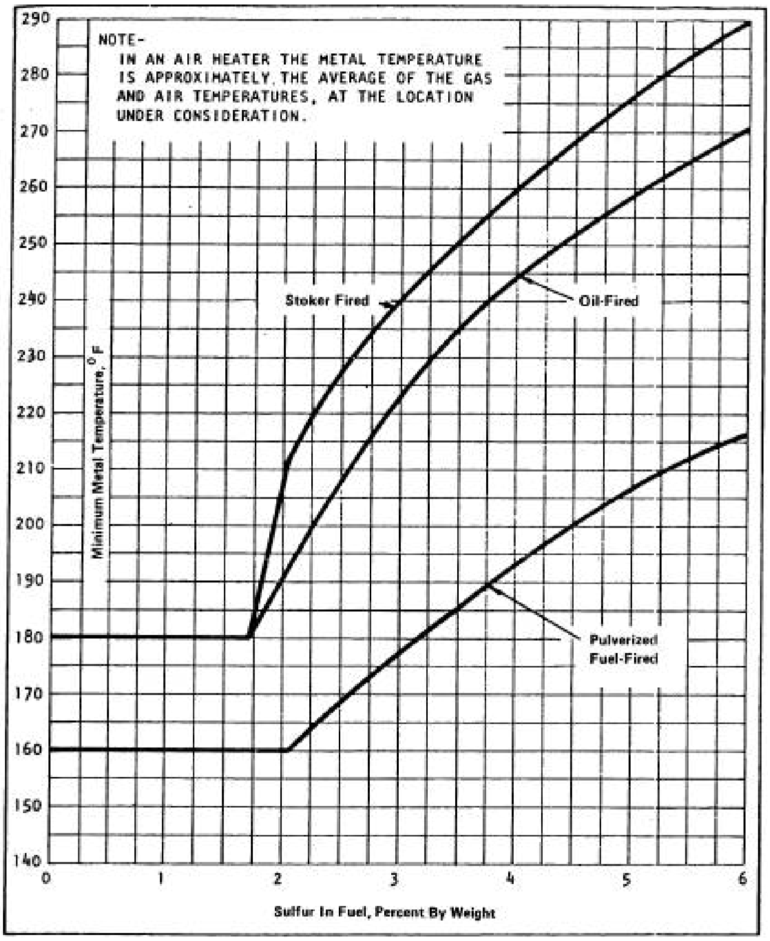

Figure 13. Required Tube Metal Temperatures According to the Percentage of Sulfur in the Fuel. [6]

Corrosion Symptoms and Prevention Methods

Metal surfaces subjected to low temperature corrosion wear over time. In some cases, the wear may be proportional across the surface. In such cases, it may be necessary to make thickness measurements with ultrasonic methods at certain intervals. In some cases, a rust-like appearance and rough surfaces may occur, as seen in Figure 14. [7]

Figure 14. Examples of Tubes Corroded by Sulfuric Acid [7]

The methods that can be applied to prevent or reduce low temperature corrosion can be divided into two as methods related to the combustion process and methods related to design.

Methods Related to the Combustion Process

In order to reduce sulfuric acid corrosion, it is necessary to carry out the combustion with the lowest excess air coefficient as possible and to use low sulfur fuels. In addition, in order to reduce the condensation effect of excess moisture, it is necessary to use low-moisture fuels, to prevent air leaks into the flue gas paths and to minimize the soot blowing process as much as possible.

Adding various additives to the fuel can also offer a separate solution. These additions are especially used in large-scale FO burning systems. Such chemical additions depend on the combustion system, environmental factors and boiler material properties. With these add-ons, the system efficiency increases as the condensation temperatures of the corrosive gases decrease, there is less accumulation on the boiler surfaces and less traction loss as the particle formation decreases, and the cleaning periods are reduced. In general, MgO, AlO, Mn or their mixtures are the most used of these additives. [4] The effect of chemical additions on the condensation (dew) temperature of sulfuric acid can be seen in Figure 15.

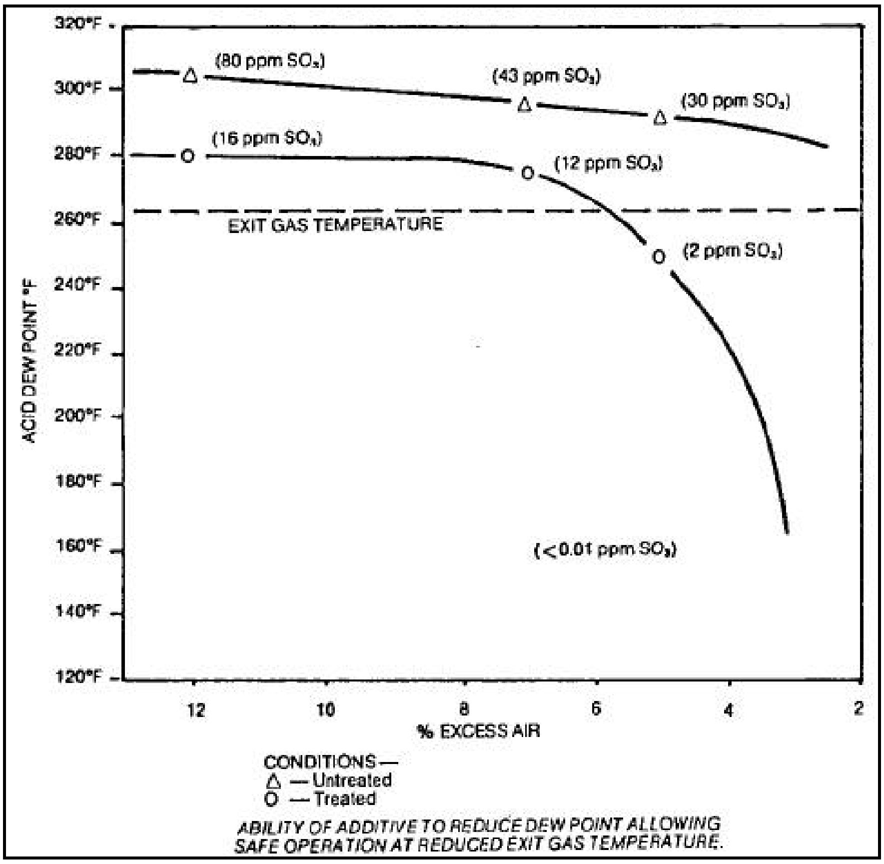

Figure 15. Effect of Chemical Additions and Excess Air on Acid Condensing (Dew)Temperatures [4]

Equipment Design Methods

Contrary to what is widely known in the market, low temperature corrosion depends on the tube metal temperature rather than the flue gas outlet temperature. Even if the gas temperature is very high, if the tube metal temperature is below the condensation temperature of the corrosive gas, condensation and corrosion will occur on the wall, albeit partially. When calculations are made with the necessary formulations, it can be seen that a temperature increase of 200 ºC on the gas side can only increase the tube metal temperature by 4-5 ºC. [10] Therefore, it is a more rational method to increase the water temperature in the tube instead of increasing the gas outlet temperature. For this reason, besides the improvements that can be made in fuel or combustion, many methods are used in the flow regulation of economizers. As a result, the main goal is to have the lowest tube metal temperature higher than the condensation temperature of the corrosive gas. The biggest disadvantage of these methods is the increase in economizer heating surfaces as the average temperature of the water side increases. A few arrangements that can be made in this direction can be seen in the figures below.

I) Preheating the feed water with an external heat exchanger and heating fluid; For example, preheating can be applied to the feed water with some steam to be taken from a heat exchanger and boiler. Thus, the inlet temperature of the water to the economizer, that is, the tube metal temperature, is increased, thereby reducing the corrosion potential. It is applied in large boilers that burn high sulfur coal and FO. (Fig. 16)

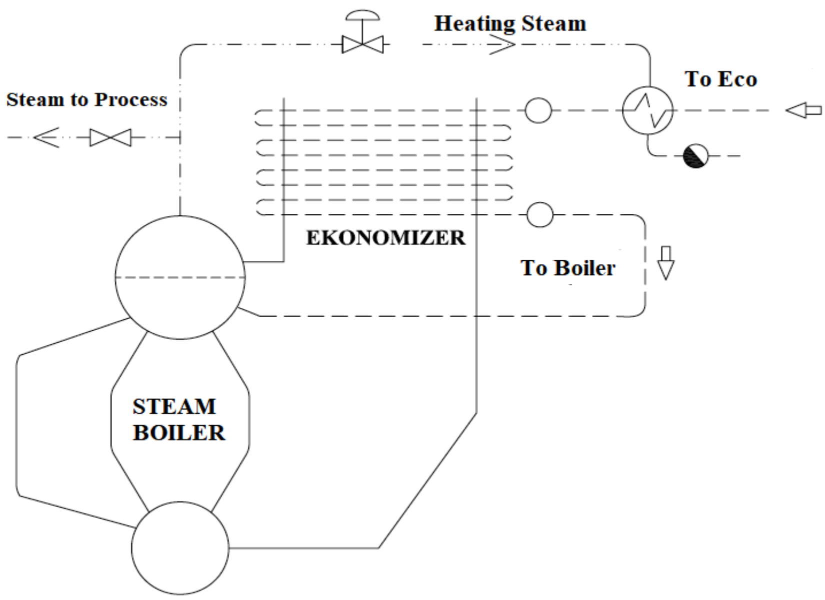

Figure 16. Preheating of Feed Water with an External Heat Exchanger.

II) Heating the inlet water with the economizer outlet water; For example, the feed water entering the economizer at a temperature of 90 ºC can be heated in a heat exchanger with the leaving water at 140 ºC and given to the economizer at a temperature of 100 - 110 ºC (Fig. 17)

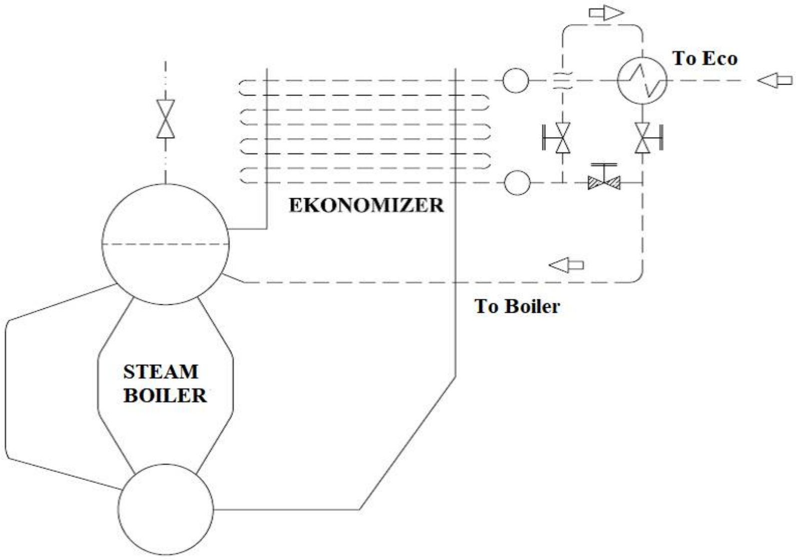

Figure 17. Heating Inlet Water with Economizer Outlet Water.

III) Raising the inlet water temperature by mixing the inlet water with outlet water; Inlet water temperature can be increased by giving some of the high temperature leaving water to the inlet of the economizer with the help of the circulation pump. Since the average water temperature in the economizer will increase, the required thermal surface will also increase slightly. Therefore, while the gas side and water side resistance will increase, the operating and investment costs will increase somewhat. However, it is widely applied in situations such as preheating the low temperature condensate coming from the condenser in power plants. (Fig. 18)

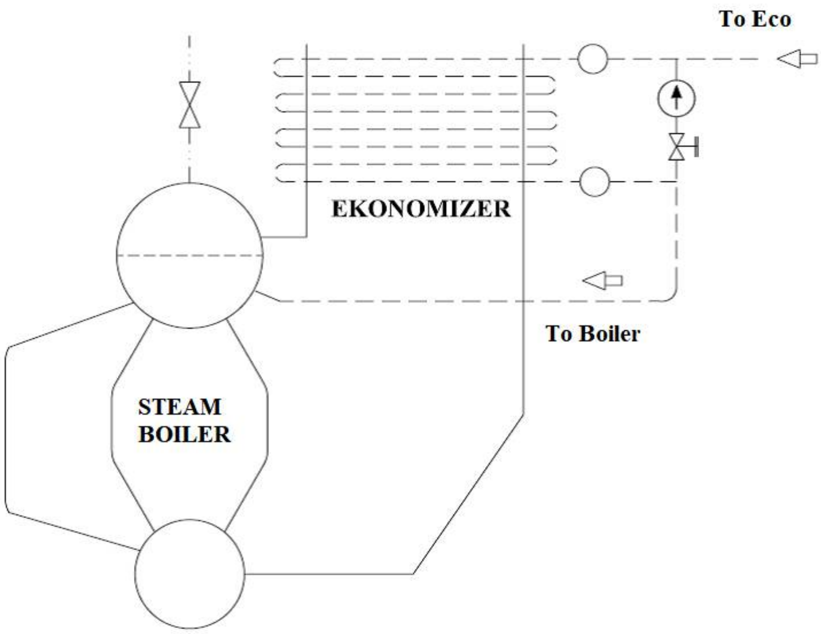

Figure 18. Mixing Some of the Economizer Outlet Water with the Inlet Water.

IV) In addition to all these, increasing the deaerator pressure is a separate method that reduces the risk of low temperature corrosion as it will increase the feed water temperature. It is a method applied especially in large industrial boilers.

CONCLUSION AND RECOMMENDATIONS

Energy recovery is now mandatory by law and is an inevitable point. In addition to the laws, there are various incentives for businesses that want to use energy efficiently. The main purpose is to reduce the use of fossil fuels, which are limited and mostly exported, as much as possible, to minimize foreign dependency, and to reduce the emissions of polluting and greenhouse gases into the atmosphere. Considering that most of the fossil fuels are consumed by heat and energy boilers in our country, the importance of the use of economizers becomes more evident.

To give a simple example; A business with 6 tons/h steam usage pays an average of 100,000 TL natural gas bill for 16 hours and 26 days of work per month without an economizer. The 5% savings to be achieved with the use of economizer means an average monthly income of 5,000 TL. Annual savings of around 50,000 - 60,000 TL will be achieved. Considering the investment cost of such an economizer, it can be said that it will pay for itself between 6 months and 1 year. However, since fuel consumption will decrease by 5%, pollutants (NO_x, SO_x) and greenhouse gases (CO_2) released into the atmosphere will also decrease at the same rate. For example, if we assume that there is 13% CO_2 by mass in the flue gas, when the necessary calculations are made according to the 16 hours and 26 days working condition, it can be said that 20 tons less CO_2 is emitted per month with the use of economizers. The same logic can be applied for nitrogen oxides and, if any, sulfur oxides. Considering that there are about 6000 steam-using enterprises in our country, it can be seen how much monetary savings and pollutant emission reductions can be made even only in steam boilers.

The important point when investing in economizer is to design a proper system according to fuel and usage temperatures. Problems may occur in an unconscious design, which causes downtime in the business. This situation causes the business to make a loss while trying to save money. In a design that will be carried out by paying attention to the above-mentioned points, especially corrosion-related problems can be minimized. In addition to minimizing the downtimes caused by the economizer in the facility, as a result, competitiveness with savings and respect for the environment are reinforced with low emissions.

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