Analysis of optimal design of low temperature economizer

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Abstract. This paper has studied the Off-design characteristic of low temperature economizer system based on thermodynamics analysis. Based on the data from one 1000 MW coal-fired unit, two modes of operation are contrasted and analyzed. One is to fix exhaust gas temperature and the other one is to take into account both of the average temperature difference and the exhaust gas temperature. Meanwhile, the cause of energy saving effect change is explored. Result shows that: in mode 1, the amount of decrease in coal consumption reduces from 1.11 g/kWh (under full load) to 0.54 g/kWh (under half load), and in mode 2, when the load decreases from 90\% to 50\%, the decrease in coal consumption reduces from 1.29 g/kWh to 0.84 g/kWh. From the result, under high load, the energy saving effect is superior, and under lower work load, energy saving effect declines rapidly when load is reduced. When load changes, the temperature difference of heat transfer, gas flow, the flue gas heat rejection and the waste heat recovery change. The energy saving effect corresponding changes result in that the energy saving effect under high load is superior and more stable. However, rational adjustment to the temperature of outlet gas can alleviate the decline of the energy saving effect under low load. The result provides theoretical analysis data for the optimal design and operation of low temperature economizer system of power plant.

1. Introduction
As the energy usage of coal-fired plants constitutes the largest proportion of the national energy consumption, conserving energy and reducing emissions in coal-fired plant are meaningful to the energy-saving strategy of China, which commonly resort to recovering waste heat of flow gas in utility boilers for being beneficial to energy conservation, economy and environment [1].

Implementing low temperature economizer systems is one of the most sophisticated and prevailing ways of recovering waste heat. For improving heat utilizing efficiency and reducing coal consumption, low temperature economizer systems are added behind air preheaters installed at the end of boilers to recover the waste heat of gas flow used to heat condensate water and then facilitate the stream-extracting action of turbines [2,3]. Currently, low temperature economizer systems have been successfully applied in the Secondary Power Plant of Changchun, the Third Power Plant of Shanghai Waigaoqiao, Longkou Power Plant and etc [4-6]. Meanwhile, many relative scholars have deeply researched energy saving effect arched the characteristics of low temperature economizer systems in various aspects; Preciously, Lin W C, et al proposed that analysing low temperature economizer systems and its thermally-economic efficiency can be achieved by introducing equivalent enthalpy drop method [7]. Han Z H, et al analyzed the thermal economic of adding low-temperature
economizer in flue duct of a boiler’s tail section to use flue gas to heat condensed water [8]. Huang X Y, et al thoroughly analysed operation optimization of low temperature economizer systems [9,10]. For low temperature economizer systems design, Ding L Q, et al carried out thermal calculations, systemic calculations and economic requirement calculations in a lot of projects and acquired a standard calculation model to calculate optimal heating squares of low temperature economizer systems [11,12]. Li B, et al adopted distributed parameter method to discover the dynamic characteristics of low temperature economizer systems and estimated safety and reliability of the systems [13]. Wang Z J, et al put forward a segmented low-temperature economizer flue gas waste heat recovery system to improve the quality of the use of extraction steam [14]. Zhang H D, et al introduced the design features and advantages of the combined system of low pressure economizer and air heater [15].

However, many existed researching energy saving effect arches only refer to the engineering application, economic efficiency and optimization of low temperature economizer systems [16-20], there is few of work that describes off-design characteristics of this system. Therefore, by selecting a domestic 1000 MW plant as a case plant, this paper investigates the variation of energy saving effect when low temperature economizer systems works in different operation conditions, and provides important data reference to designing low temperature economizer systems, recovering waste heat of boilers, and even optimizing or modifying the entire boilers.

2. The integrated way of low temperature economizer systems

2.1. Introduction of the case plant

This paper selected a typical 1000 MW ultra supercritical plant as researching energy saving effect arch objective, which includes 1013-28/600/620 single – regeneration condensing turbine with 9-stage regenerator and 1-stage externally-installed stream cooler. Figure 1 symbolizes the schematic thermal system of the case plant. The main parameters of coal quality analysis are provided in table 1, the main thermodynamic parameters of the boiler are in table 2 and those of Regenerative Heating System in tables 3-6.

![Figure 1. A schematic thermal system of the case plant.](image)

**Table 1.** Main parameters of coal quality analysis.

| Item     | Car (%) | Har (%) | Oar (%) | Nar (%) | Sar (%) | Mar (%) | Qnet, ar MJ/kg |
|----------|---------|---------|---------|---------|---------|---------|----------------|
| Value    | 57.33   | 3.26    | 9.43    | 0.61    | 0.63    | 10.66   | 21.23          |

Car-coal as received coal; Har- Hydrogen as received coal Oar-Oxygen as received coal; Nar-Nitrogen as received coal; Sar-Sulfur as received coal Mar-Moisture as received coal

**Table 2.** The main thermodynamic parameters of the boiler.

| Load     | 100%  | 90%   | 75%   | 50%   |
|----------|-------|-------|-------|-------|
| Fuel consumption/t/h | 366.35 | 331.44 | 278.81 | 193.15 |
| Feedwater heater number | 5# | 6# | 7# | 8# | 9# |
|------------------------|----|----|----|----|----|
| Extraction temperature °C | 297.1 | 247.5 | 192.2 | 88.1 | 63.1 |
| Extraction pressure/MPa | 0.51 | 0.33 | 0.20 | 0.06 | 0.02 |
| Outlet condensed water temperature/°C | 150.1 | 133.7 | 117.0 | 81.6 | 57.60 |
| Outlet condensed water pressure/MPa | 1.12 | 1.15 | 1.19 | 1.23 | 1.26 |
| Condensed water flow/kg/s (lb/s) | 510.7 | 510.7 | 510.7 | 453.5 | 453.5 |
| (1123.54) | (1123.54) | (1123.54) | (0.9977) | (0.9977) |
| Dewatering temperature/°C | 139.3 | 122.6 | 119.5 | 84.4 | 39.1 |

Table 5. The main thermodynamic parameters of the regenerative heating system at 75% load.

| Feedwater heater number | 5# | 6# | 7# | 8# | 9# |
|------------------------|----|----|----|----|----|
| Extraction temperature °C | 301.2 | 252.1 | 197.1 | 83.7 | 57.4 |
| Extraction pressure/MPa | 0.43 | 0.28 | 0.17 | 0.05 | 0.02 |
| Outlet condensed water temperature/°C | 143.8 | 128.1 | 112.1 | 77.6 | 54.7 |
| Outlet condensed water pressure/MPa | 0.98 | 1.01 | 1.03 | 1.06 | 1.08 |
| Condensed water flow/kg/s (lb/s) | 425.1 | 425.1 | 425.1 | 379.6 | 379.6 |
| (935.22) | (935.22) | (935.22) | (835.12) | (835.12) |
| Dewatering temperature/°C | 133.7 | 117.7 | 114.6 | 80.4 | 39.3 |

Table 6. The main thermodynamic parameters of the regenerative heating system at 50% load.

| Feedwater heater number | 5# | 6# | 7# | 8# | 9# |
|------------------------|----|----|----|----|----|
| Extraction temperature °C | 306.1 | 257.9 | 203.6 | 88.7 | 50.9 |
| Extraction pressure/MPa | 0.30 | 0.19 | 0.12 | 0.03 | 0.01 |
| Outlet condensed water temperature/°C | 130.9 | 116.5 | 101.7 | 69.0 | 48.1 |
| Outlet condensed water pressure/MPa | 0.74 | 0.75 | 0.77 | 0.78 | 0.79 |
| Condensed water flow/kg/s (lb/s) | 287.4 | 287.4 | 287.4 | 259.2 | 259.2 |
| (632.8) | (632.8) | (632.8) | (570.24) | (570.24) |
| Dewatering temperature/°C | 122.1 | 107.3 | 104.3 | 71.8 | 39.8 |

As shown in table 2 the outlet gas temperature of air preheater is relatively high, correspondingly, the heat loss of gas flow is significant, which means that heat energy cannot be efficiently used. According to tables 3-6, with the decreases in working load, the extraction pressure of each stage in regenerative heater gradually decreased, consequently, the amount of utilizable thermal energy in
extracted stream reduced. Meanwhile, in the regenerative heater, the outlet temperatures and the amount of condensate water in each grades decreased as the working load reduced.

2.2. The integrating way and optimizing law of low temperature economizer systems

Given that in the boiler of the case plant the heat loss of outlet gas flow is significant, implementing low temperature economizer systems at the flue (behind air preheater) to heat condensate water would successfully decrease the gas temperature and heat loss of gas flow, and then would facilitate the stream-extracting action of turbine. Consequently, rising plant efficiency and reducing coal consumption would be achieved. In addition, adding low temperature economizer systems would decrease inlet gas temperature of low-electrostatic-precipitators and desulfurization tower, which satisfies the requirement of improving dust-removing efficiency and reducing water consumption during desulfurization process.

After comprehensively considering the energy saving effect and practical circumstances of case plant under various operating conditions, LETS was installed in series between Stage 7 and Stage 8 of low-pressure regenerative heater, as shown in figure 2.

![Figure 2. Integrated schematic of low temperature economizer of the case plant.](image)

There are two basic laws which should be followed during system operation optimization:

- for avoiding low-temperature corrosion, the designed outlet temperature of low temperature economizer systems should not be lower than 95°C.
- for feasibility consideration, the Heat Transfer Temperature Difference of low temperature economizer systems in each operating condition should be above 20°C.

3. Thermodynamic analysis of low temperature economizer systems under off-design working conditions

3.1. Thermodynamic calculation of low temperature economizer systems

Based on the integration way and operation optimization laws mentioned in Chapter 1.2, this paper mainly analyses comprehensive performances of low temperature economizer systems under two working modes listed as follows.

Mode 1: low temperature economizer systems operate with fixed outlet gas temperature, which means that the temperatures of each working condition are fixed as 100°C.

Mode 2: low temperature economizer systems operates with consideration of both average temperature differences and outlet gas temperatures, which means that the average temperature difference of heat transfer in low temperature economizer systems is assumed 20°C with the precondition that outlet gas temperature would not be lower than 95°C. Firstly, this paper carries out thermodynamic calculations under the assumption that the average temperature difference of heat transfer in low temperature economizer systems is 20°C. Then, if the outlet gas temperature is higher
than 95°C, results are acceptable. If the outlet gas temperature is lower than 95°C, calculate under the assumption that outlet gas temperature is 95°C.

This paper carries out off-design thermodynamic calculations of low temperature economizer systems under the two modes and acquires the corresponding parameters respectively listed in tables 7 and 8.

Table 7. Main parameters under each load of the low temperature economizer system while operating mode 1.

| Load            | 100% | 90% | 75% | 50% |
|-----------------|------|-----|-----|-----|
| Inlet flue gas temperature/°C | 121  | 120 | 115 | 109 |
| Outlet flue gas temperature/°C | 100  | 100 | 100 | 100 |
| inlet condensed water temperature/°C | 83.98 | 81.56 | 77.54 | 68.94 |
| Outlet condensed water temperature/°C | 94.17 | 91.56 | 85.47 | 74.22 |
| Heat transfer temperature difference/°C | 20.96 | 23.08 | 25.83 | 32.88 |
| Heat transfer amount/kW | 21.87 | 19.30 | 12.75 | 5.76 |

Table 8. Main parameters under each load of the low temperature economizer system while operating mode 2.

| Load            | 100% | 90% | 75% | 50% |
|-----------------|------|-----|-----|-----|
| Inlet flue gas temperature/°C | 121  | 120 | 115 | 109 |
| Outlet flue gas temperature/°C | 98.8 | 96.2 | 95  | 95  |
| inlet condensed water temperature/°C | 84.0 | 81.6 | 77.5 | 68.9 |
| Outlet condensed water temperature/°C | 94.7 | 93.4 | 88.1 | 77.1 |
| Heat transfer temperature difference/°C | 20.0 | 20.0 | 21.9 | 28.9 |
| Heat transfer amount/kW | 23.12 | 22.95 | 16.99 | 8.95 |

Table 7 shows the results of Mode 1 that the outlet gas temperatures under each working condition are above 100°C and the Heat Transfer Temperature Difference above 20°C, which guarantees the feasibility of the system. Meanwhile, the temperature difference gradually increases as a result of the decrease in working load, then the amount of transferred heat decreases; Transferred heat can reach 21.87 MW under full working load, while it is merely 5.76 MW under half load.

Table 8 suggests the results in Mode 2, the outlet gas temperatures under each working load are respectively 98.8°C/96.2°C/95°C/95°C. Regarding Heat Transfer Temperature Difference, when the working loads are 100% or 90%, temperature differences keep at 20°C. When the loads are decreased at 75% or 50%, temperature differences are separately 21.9°C and 28.9°C. All of the parameters satisfy the operation optimization law and guarantee its feasibility. As the working load gradually becomes half from its full value, the temperature difference does not change at the first stage and then increases. Meanwhile, with the reduction of working load, the amount of transferred heat slowly decreases, while the range of decreasing is not as large as that in Mode 1.

3.2. Energy saving effect analysis

Carrying out heat balance analysis of power plant which has installed low temperature economizer systems, the energy saving effect of the two operating modes under different working conditions can be acquired and collected in tables 9 and 10.

Table 9. Calculation results of each load while operating mode 1.

| Load            | 100% | 90% | 75% | 50% |
|-----------------|------|-----|-----|-----|
| Initial generator power/MW | 1012.0 | 910.8 | 759.0 | 506.0 |
| Load       | Initial generator power/MW | Low Temperature Economizer System generator power/MW | generator power increment/MW | Initial system thermal efficiency/% | Low Temperature Economizer System thermal efficiency/% | Thermal efficiency increment/% | Initial coal consumption g/kWh*(l b/kWh) | Low Temperature Economizer System coal consumption/g/kWh*(l b/kWh) | coal consumption reduce/g/kWh*(l b/kWh) |
|------------|---------------------------|-----------------------------------------------------|-------------------------------|------------------------------------|---------------------------------|-------------------------------|-----------------------------------------|--------------------------------------------|------------------------------------------|
| 100%       | 1012.0                    | 1016.3                                               | 4.3                           | 46.88                              | 47.08                            | 0.20                          | 261.97                                  | (0.576334)                                 | 1.11                                      |
| 90%        | 910.8                     | 914.6                                                | 3.8                           | 46.70                              | 46.89                            | 0.19                          | 262.96                                  | (0.578512)                                 | 1.09                                      |
| 75%        | 759.0                     | 761.4                                                | 2.4                           | 46.32                              | 46.47                            | 0.15                          | 265.10                                  | (0.58322)                                  | 0.85                                      |
| 50%        | 506.0                     | 507.0                                                | 1.0                           | 44.86                              | 44.95                            | 0.09                          | 273.75                                  | (0.60225)                                  | 0.54                                      |

Table 10. Calculation results of each load while operating mode 2.

According to table 9, compared with the original system (without low temperature economizer systems), all of the systems which installed low temperature economizer systems operate with significant energy saving effect under Mode 1. This effect was alleviated by reducing working loads; energy saving effect is salient under full load condition, with an increase of 0.2% in heat efficiency of case plant and a decrease of 1.11 g/kWh (0.002442 l b/kWh) in coal consumption. This effect was slightly abated when the load becomes 90%, with the decrease of 1.09 g/kWh (0.002398 l b/kWh) in coal consumption. The influence of reducing load, which would abate energy saving effect, can clearly be seen when the load decreases to 75% where coal consumption is 0.75 g/kWh (0.00165 l b/kWh). Finally, energy saving effect in half load is the worst, since the increase in heat efficiency becomes 0.09% and the decrease in coal consumption is only 0.54 g/kWh (0.001188 l b/kWh).

It can be seen in table 10 that under Mode 2, low temperature economizer systems operates with considerable energy saving effect in different working loads; the performance of saving energy is optimized under the 90% load. The effects are similar between the load of 100% and that of 75%, and the amount of decreases in coal consumption are 1.18 g/kWh (0.002596 l b/kWh) and 1.13 g/kWh.
(0.002486 l/kWh) respectively. Under the condition of half loading, the value becomes 0.84 g/kWh (0.001848 l/kWh), which is smaller than that under the condition of 90% loading by 0.45 g/kWh (0.000991 l/kWh). Generally, the performance of Mode 2 under each working condition is superior to that of Mode 1. In addition, with the increasingly decreased working load, the priority of Mode 2 in saving energy became apparent; Under 75% and 50% loading, the value of decrease of coal consumption in Mode 2 are 1.13 g/kWh and 0.84 g/kWh (0.001848 l/kWh) respectively, which are larger than those in Mode 1 by 33% and 56% separately.

3.3. Comparison of energy-saving effect in off-design circumstances

As of the results about energy-saving effect shown in 2.2, the original case plant is compared with the system which adopts low temperature economizer systems, and then the curve of the reduction of coal consumption rate along with the changing of the load is acquired in figure 3.

![Figure 3](image)

**Figure 3.** The curve of the reduction of coal consumption rate along with the changing of the load.

From figure 3, apparently, system operates with energy saving effect in both Mode 1 and Mode 2. Comparing the two curves, with the decrease in working load, the curve which symbols the decrease in coal consumption gradually declines in Mode 1; when the load is above 90%, the curve is relatively plain while it sharply decreases once the load is below 90%. In Mode 2, the curve which symbols the reduction of coal consumption rises firstly and then falls with the load decrease. The optimal energy-saving performance occurred when the load is 90%, which means that the reduction of coal consumption is highest. When the load is below 90%, there is a more significant decrease in the reduction of coal consumption. And when the load becomes 75%, the value of coal consumption reduction value is as same as that in full loading condition. Generally, the decreasing trend of the curve which symbols the reduction of coal consumption in Mode 2 is more gentle than that in Mode 1, and energy saving effect of Mode 2 is superior to that of Mode 1 under each working condition. Accordingly, energy saving effect of low temperature economizer systems is similar under high loading conditions, while it would be sharply abated during low loading circumstance. Therefore, energy saving effect of low temperature economizer systems would affect better if the plant keeps high loading operation. Meanwhile, after comparing the two curves, it has been discovered that energy saving effect under low loading circumstances can be improved by adjusting the outlet gas temperature of low temperature economizer systems.

4. **Cause analysis of energy saving effect changes in off-design conditions**

4.1. *Heat transfer temperature differences and temperature ranges of flue gas heat rejection*
The level of thermodynamic completion of low temperature economizer systems significantly influences the energy saving performance in off-design working conditions, which is often reflected by the values of Heat Transfer Temperature Difference. Besides, temperature range of flue gas heat rejection reflects the amount of remained thermal energy to some extent, which is closely relative to the energy-saving performance of system. Figures 4 and 5 suggest the off-design Heat Transfer Temperature Difference and the temperature ranges of Flue Gas Heat Rejection under both the two operation modes.

Figure 4. The curve of heat transfer temperature difference with the changing of the load.

Figure 5. The curve of flue gas heat release temperature with the changing of the load.

As of figure 4, with the decrease in working load, heat transfer temperature difference gradually increases, energy loss correspondingly increases, and the degree of thermodynamic completion drops. In Mode 2, Heat Transfer Temperature Difference is in plateau firstly with the loading reduction and then increases. When the load is below 90%, as the load decreased continuously, Heat Transfer Temperature Difference slowly increases, as well as energy loss. Consequently, the degree of thermodynamic completion of low temperature economizer systems decreases, which influences the energy saving effect of the entire system.

Figure 5 suggests the relation between temperature ranges of Flue Gas Heat Rejection and working loads. In Mode 1, when the working load is reducing, the temperature difference is decreasing as well, then the recoverable waste heat is decreased. In Mode 2, the temperature range firstly rises and then declines with the increasingly reduced working load. The peak value, which means there is the greatest amount of recoverable waste heat, occurs when the load is 90%. Comparing the two curves of temperature range, it can be seen that the ranges in Mode 2 are always higher than those in Mode 1. Therefore, energy saving effect of Mode 2 is superior to that of Mode 1. Generally, when the load keeps above 75%, the variation of heat transfer temperature difference is slight, and there is not significant difference in the degree of thermodynamic completion of low temperature economizer systems. Meanwhile, given that temperature range of Flue Gas Heat Rejection is relatively high, which means that the amount of recoverable waste heat is relatively high, system operates with efficient energy-saving performance. While under low-loading conditions, the variation of Heat Transfer Temperature Difference becomes greater than that in high load condition, then the degree of thermodynamic completion is abated. Moreover, since the temperature range of Flue Gas Heat Rejection is relatively low as well, system cannot operate with highly-efficient energy-saving performance. Through analysing the two modes and operating the optimized system, it can be discovered that adjusting outlet gas temperature would improve the performance of low temperature economizer systems in low-loading conditions, which means that system can still keep well energy saving effect in low-loading operation. Importantly, safety should not be compromised in all
4.2. The variation of gas flow rates

The rate of gas flow, which passes through low temperature economizer systems, significantly influences the amount of transferred heat. Figure 6 shows the outlet Gas Flow Rate of air preheater under each working condition of the case plant.

From figure 6, with the decrease in working load, the curve which symbols the outlet Gas Flow Rate of air preheater proportionally decreases; in both Mode 1 and 2, the rates of gas flow, which passes through the air preheater, gradually reduce as the load decreases, then the total amount of heat rejection in gas flow decreases as well. Therefore, the influence of Gas Flow Rate on the two modes would not be taken into account. However, the influence of this flow rate on the energy saving effect of low temperature economizer systems is unneglectable. With the constantly decreased load, the flow rate proportionally reduces, which causes a gradually declined amount of transferred heat in low temperature economizer systems. As a consequence, energy saving effect is abated.

![Figure 6. The curve of flue gas flow rate of air preheater outlet with the changing of the load.](image1)

![Figure 7. The curve of the amount of waste heat recovery of fuel unite with the changing of the load.](image2)

4.3. The amount of waste heat recovery (Kilojoules per Kilograms)

The amount of waste heat recovery should be considered during analysing energy saving effect of low temperature economizer systems, although it is incomprehensive that only comparing waste heat recovery amount under different working conditions. With the changes in working load, there are also variations of the required fuel amounts and the required outlet gas temperatures of the boiler. Therefore, it is unreasonable that only considering the parameter – the amount of waste heat recovery – to analyse the causes of the change in energy saving effect. Consequently, a standardised unit (kilojoules per kilograms) has been introduced for further energy saving effect analyses. Figure 7 shows the amount of waste heat recovery of low temperature economizer systems in off-design conditions under both the two modes.

In figure 7, both the two curves are plain under high working loads and are sharp under low loads. The heat recovery amount is actually the superposition of the Gas Flow Rate variation under each load and the temperature range variation of Flue Gas Heat Rejection. In Mode 1, the amount of waste heat recovery (kilojoules per kilograms) declines as the load decreases; in high loading condition there is only slight change in the heat recovery amount, while the change that being decreased in this amount gets increasingly fast as the load reduces. In Mode 2, as working load declines as well, the recovery amount rises firstly and then declines. Furthermore, this figure insignificantly changes under high load operation, and dramatically drops once the load is below 75%. As of the results, in both the two modes, the amounts of recoverable waste heat (per kilograms) are higher under high load conditions than
those under low loads, which can substitute more extracted stream from turbines to achieve better energy-saving performance. Above all, more waste heat can be recovered by keeping low temperature economizer systems operates under high load conditions.

As of the comparison between figures 4 and 7, the variation trend of waste heat recovery amount is as same as that of temperature ranges, which verifies that being narrow of the heat rejection temperature range under low working loads is the main cause of being small of the waste heat recovery amount. Furthermore, the comparison between figures 3 and 7 suggests that the variation trend of heat recovery amount is as approximately same as that of the final energy saving effect (the decrease in coal consumption), which means that the decrease in heat recovery amount (per kilograms) caused by being narrow of Flue Gas Heat Rejection temperature range and being reduced of the gas flow amount is the main reason of the abated energy-saving performance under low working loads in low temperature economizer systems.

5. Conclusion
This paper discusses the off-design characteristics of low temperature economizer systems under two operation modes – one is to fix exhaust gas temperature, the other mode is taking the average temperature difference and the exhaust gas temperature into account – by thermodynamically analysing and comparing the energy-saving performances under off-design working conditions. Besides, this paper also investigates causes of the changes in energy saving effect of low temperature economizer systems under off-design working conditions. In conclusion, the results demonstrate that:

- Under the operating mode with fixed outlet gas temperature, in the case plant which installs low temperature economizer systems, when the working load is halved from full state energy saving effect is apparently abated. Meanwhile, the amount of decrease in coal consumption reduces from 1.11 g/kWh (0.002442 l/b/kWh) (under full load) to 0.54 g/kWh (0.001188 l/b/kWh) (under half load). The effect of energy saving in half load is only 45% of that in full load. Regarding the changing speed of energy saving effect, in the high loading circumstances, this effect slowly changes while it sharply drops once the load becomes low.

- Under the operating mode which takes both the average temperature difference and the exhaust gas temperature into account, as the load also declines, the energy-saving effect is firstly intensified and then abated. The optimal energy-saving performance occurs when the load is 90%, which also symbols an increase in heat efficiency of 0.23% and a decrease in coal consumption of 1.29 g/kWh (0.002838 l/b/kWh). When the load decreases from 90% to 50%, the decrease in coal consumption reduces from 1.29 g/kWh (0.002838 l/b/kWh) to 0.84 g/kWh (0.001848 l/b/kWh). Under high-loading conditions, the energy-saving effects of low temperature economizer systems are insignificantly influenced by the load variations. As the load continuously decreases, the energy-saving performance sharply abates. Therefore, well energy-saving performances can be achieved by keeping low temperature economizer systems operating under high working loads.

- In conclusion, the energy-saving performance is relatively well under higher-loading operations in both the two modes, which means that it would be considerably abated under low-loading operations. There are two main causes of this phenomenon: Firstly, the inlet gas flow temperature of low temperature economizer systems significantly decreases when the working load becomes low, meanwhile, the outlet temperature of low temperature economizer systems should be high enough to prevent from low-temperature corrosion. Secondly, the amount of flue gas reduces under increasingly low working load. Both the two points would cause a considerable decrease in the amount of recoverable waste heat which is exhausted from air preheater, furthermore, would abate the energy-saving performance of the system.

- Both Heat Transfer Temperature Difference of low temperature economizer systems and the outlet gas temperatures are considered in Mode 2, with the preconditions of guaranteeing safety and minimum heat transfer temperature difference, slightly reducing the outlet gas temperature of low temperature economizer systems (under low loading condition) would extend the
temperature range of flue gas heat rejection in low temperature economizer systems. Compared with the energy-saving performance in Mode 1, this adjustment improves that in Mode 2, particularly under low working load conditions.

In conclusion, when the system is needed to operate under low working load conditions, properly reducing the final outlet gas temperature would considerably improve the working performance of low temperature economizer systems, with the precondition of safety and minimum heat transfer temperature difference.

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