

Article

Pressure Drop Optimization of the Main Steam and Reheat Steam System of a 1000 MW Secondary Reheat Unit

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Abstract: The pressure drop of a main steam and reheat steam system should be optimized during the design and operation of a thermal power plant to minimize operation costs. In this study, the pressure drop of the main steam pipe and reheat steam pipe of a 1000 MW secondary reheat unit are optimized by modulating the operation parameters and the cost of operation is explored. Optimal pipe specifications were achieved by selecting a bend pipe and optimizing the pipe specifications. The pressure loss of the main steam pipeline was optimized to 2.61% compared with the conventional pressure drop (5%), the heat consumption of steam turbine was reduced by about 0.63 kJ/(kW·h), the standard coal consumption was minimized by about 0.024 g/(kW·h), and the total income in 20 years is approximated to be CNY 217,700. The primary reheat system was optimized to 4.88%, the steam turbine heat consumption was reduced by about 7.13 kJ/(kW·h), the standard coal consumption decreased by about 0.276 g/(kW·h), and the total income in 20 years is projected to be CNY 20.872 million after the optimization of the pressure drop. The secondary reheat system was optimized to 8.13%, the steam turbine heat consumption was reduced by about 7.86 kJ/(kW·h), the standard coal consumption decreased by about 0.304 g/(kW·h), and the total income in 20 years is projected to be CNY 22.7232 million after the optimization of the pressure drop. The research results of the present study provide a guide for the design and operation of secondary reheat units to achieve an effective operation and minimize costs.

Keywords: 1000 MW secondary reheat unit; main steam and reheat steam system; pressure drop optimization



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1. Introduction

The pressure drop of a main steam and reheat steam system is an important performance evaluation index when designing a thermal power plant [1–3]. The design and operation of the unit should ensure the optimization of the pressure drop of the main steam and reheat steam system to minimize operation costs [4,5]. An increase in the inlet pressure of the main throttle valve of the steam turbine reduces the heat rate of the unit and improves the thermal efficiency of the unit [6–9]. Therefore, it is imperative to determine the steam inlet parameters of the steam turbine at the bidding and selection stages of the main engine, especially for supercritical units and ultra-supercritical units [10–13]. Moreover, the thermal efficiency of the unit can be further improved by optimizing the specifications and accessories of the four pipelines, especially the main steam and reheat steam pipelines [1,14]. Li (2018) proposed a new design scheme that eliminates the high- and medium-pressure cylinder extractions and adopts the dual-machine regenerative cycle system of multi-stage small steam turbine extraction based on the design scheme of the

conventional 1000 MW secondary reheat unit [15]. Li et al. (2019) explored and compared the thermal absorptions of superheated steam and primary and secondary reheat steam, and the findings showed that the poor design of the proportion of heat-absorbing area results in low reheat steam temperatures [16]. Wang et al. (2022) increased the number of back-pressure extraction steam turbine (BEST) stages from four to eight, and the feasibility, variable working condition characteristics, and thermal economy of the unit under different BEST stages were evaluated based on the design of a secondary reheat unit equipped with BEST to determine the optimal stages of the BEST scheme [17].

The medium flow rate of the high-pressure water supply pipeline is low; thus, it has little impact on pressure loss [18–22]. Therefore, the medium flow rate was not explored in the present study. The effective design of a thermal heat system should meet the requirements of a flow rate of 2~6 m/s [23,24]. The design code of large- and medium-sized thermal power plants (GB 50660-2011) stipulates that “the pressure drop from the outlet of boiler superheater to the inlet of steam turbine should not be higher than 5% of the rated inlet pressure of steam turbine” [2,25]. The total pressure drop of the reheat steam system for the critical parameter unit should be within 7~9% of the exhaust pressure of the high-pressure cylinder under the rated power conditions of steam turbine [8,26,27]. Moreover, the pressure drop of the cold reheat steam pipeline, reheater, and hot reheat steam pipeline should be 1.3~1.7%, 3.5~4.5%, and 2.2~2.8% of the exhaust pressure of the high-pressure cylinder under the rated power conditions of the steam turbine [2,28–30]. These features are aimed at optimizing the conventional primary reheat unit. The present project is a secondary reheat unit, which is not covered by the existing specifications. The total pressure drop for the low-pressure reheat system in the secondary reheat unit should not exceed 12% of the exhaust pressure of the high-pressure cylinder under the rated power conditions of the steam turbine. The stated specifications are the benchmark values for the optimization of the present system. The optimized pressure drop was compared with the above data from previous designs to obtain the optimal heat consumption value.

Previous studies report that the heat consumption of the main engine plant can be reduced by approximately 0.10~0.15% when the main steam pressure is increased by 1 MPa [31,32]. The inlet pressure of the steam turbine increases and the heat consumption of the steam turbine is reduced if the output pressure of the boiler remains unchanged and the pressure drop of the main steam pipeline is reduced [26,33,34]. The pressure drop of the reheat system has a significant impact on the heat consumption of the steam turbine. The heat consumption can be reduced by about 0.25% if the pressure drop of the reheat system is reduced from 9% to 7% [35,36]. Therefore, it is imperative to optimize the pressure drop of the main steam and reheat steam system of the 1000 MW Ultra Supercritical Unit in the project. The energy consumption and emission of pollutants by thermal power plants significantly affects the environment. The increase in world population has resulted in an increase in power consumption. Therefore, studies should explore various strategies to increase energy production, while protecting the environment as well as reducing production costs. The utilization of a double reheat system improves thermal effectiveness and achieves the requirements of steam humidity of low-pressure pipes. Moreover, a double reheat steam turbine increases the dryness of the steam pipelines and minimizes the corrosion of the system, thus reducing the cost of replacement. The present study seeks to explore the optimal parameters for reducing operation costs in thermal plants by evaluating different specifications for the pipeline of the steam system, including diameter and layout optimization.

In the present study, the pressure drop of the main steam pipeline and reheat system pipeline was alleviated by optimizing pipeline specifications, adopting a simmer bend pipe. The most optimal specifications of the main steam pipeline and reheat system pipeline of the project were determined through the comparison of technical parameters and economic factors.

2. Overview of the Study System

The construction scale of the project was a 2×1000 MW Ultra Supercritical secondary reheat coal-fired generator set installed and constructed simultaneously with flue gas desulfurization and denitration devices. The whole plant achieved a zero discharge of wastewater. The parameters of the unit in the current study were limited within the service temperature range of the existing mature materials of the conventional parameters of the secondary reheat unit. Notably, the boiler outlet parameters were temporarily increased to 32.24 MPa/610 °C/625 °C/622 °C, and the initial parameters of the steam turbine were temporarily increased to 31 MPa/605 °C/622 °C/620 °C. The piping and instrumentation diagram (P&ID) of the main steam and reheat steam system is presented in Figure 1.

2.1. Boiler Parameters

The pressure, temperature, flow, and other parameters of the main steam and reheat steam of the boiler corresponded to the parameters of the steam turbine. The boiler maximum continuous rating (BMCR) matched the valve whole open rating (VWO) working conditions of the steam turbine. The detailed parameters were determined according to the bidding status of the main engine. The main technical parameters were as shown below:

Maximum continuous evaporation: 3015 t/h;
Steam pressure at the superheater outlet: 32.24 MPa (a);
Superheater outlet steam temperature: 610 °C;
Steam temperature at the primary reheat outlet: 625 °C;
Secondary reheat outlet steam temperature: 622 °C;
Guaranteed boiler efficiency: 95.2%;
Ignition mode: plasma ignition.

2.2. Turbine Parameters

The turbine used in this study was an ultra-supercritical, secondary intermediate reheat, single shaft, five-cylinder four exhausts, double back pressure, condensing type, with twelve stage regenerative steam extraction. The parameters of the turbines were as follows:

Nameplate power: 1000 MW;
Full open power of the main steam valve (VWO working conditions): 1067.963 mw;
Main steam flow (VWO working conditions): 3015 t/h;
Rated steam pressure adjacent to the main steam valve: 31 MPa (a);
Rated steam temperature adjacent to the main steam valve under the rated conditions: 605 °C;
Rated steam temperature adjacent to the primary reheat steam inlet valve under the rated conditions: 622 °C;
Rated steam temperature adjacent to the secondary reheat steam inlet valve under the rated conditions: 620 °C;
Exhaust pressure under the rated conditions: 4.4 kPa (a);
Exhaust pressure in summer: 9.2 kPa (a);
Rated speed: 3000 r/min.

2.3. Generator Parameters

A three-phase synchronous steam turbine generator was used in the present study. The parameters of the generator were as follows:

Rated output power: 1000 MW;
Rated power factor: 0.9 (lagging);
Rated voltage: 27 KV;
Rated frequency: 50 Hz;
Rated speed: 3000 r/min;
Stator coil wiring mode: YY;
Cooling mode: water hydrogen;
Excitation mode: self-shunt static excitation;
Efficiency (guaranteed value): $\geq 99\%$.

3. Methodology

3.1. Strategies for Alleviating Pressure Drop

Pipeline pressure drop refers to the sum of pipeline flow resistance, kinetic energy change, and gravitational potential energy change. The flow resistance comprises frictional resistance and local resistance. Reducing the pipeline pressure drop improves the thermal efficacy of the unit, generates more power, and ultimately reduces the operation cost of the power plant. The following measures were taken to reduce the pressure drop of the main steam system and reheat system:

(1) The reasonable selection of pipe specifications of the main steam and reheat steam system.

A larger inner diameter of the pipe is correlated with a smaller pressure drop. Therefore, the appropriate increase in the inner diameter of the pipeline is the most effective approach to minimize pressure drop. However, the main steam and reheat steam pipelines are made of alloy steel, characterized by a high cost. This implies that increasing the inner diameter of the pipeline inevitably increases the initial cost. Therefore, various comprehensive comparisons of the technical parameters and economic factors should be made to reasonably select the best specifications of the main steam and reheat steam pipelines.

(2) The optimization of the pipe length of the main steam, reheat hot section, and reheat cold section.

The resistance along the pipeline is directly correlated with the length of the pipeline. In the current study, the equipment pipeline layout of the main power room was reasonably optimized, and the size of the main power room as well as the length of six pipelines were reduced to lower the pipeline resistance and the initial cost.

(3) The adoption of the inner diameter pipe and selection of appropriate pipe roughness.

The equivalent roughness of the pipeline significantly influences the resistance along the pipeline during resistance calculations. Notably, the equivalent roughness of the pipeline produced by various processes is different. The control inner diameter pipe was imported from Europe and America and was selected for the main steam and reheat steam pipelines of the project. The equivalent roughness of steel pipe or cast iron pipe recommended by the United States is $\%_o = 0.0457$ mm, which markedly reduces the resistance of the pipeline compared with $\%_o = 0.2$ mm, which was reported in the standards of the former Soviet Union.

(4) There was no flow-measuring nozzle installed on the main steam pipeline to reduce its pressure drop.

(5) The Y-type tee was optimized to minimize the local resistance.

(6) A bend pipe was used instead of an elbow pipe if the space of the pipeline layout was enough. The bending radius of the elbow pipe was 1.5 times the pipe diameter, whereas the bending radius of the bend pipe was 3 times the pipe diameter. This implies that the local resistance of the bend pipe was significantly smaller than that of the elbow pipe.

3.2. Pressure Drop Calculation

The given pipe diameter in the section for the selection of pipeline specifications was adopted to calculate the amount of heat consumption (converted to the annual coal cost difference); then, the pipeline specifications (converted to the initial investment difference of the pipeline) were calculated. The economically optimized pipe diameter was selected after the comprehensive comparison and selection of the parameters. In addition, the benefit of using bend pipe technology was explored. The cost of the cold section pipeline was lower compared with that of the hot section pipeline. This implies that appropriately increasing the diameter of the cold section pipeline does not significantly increase the cost of the project. However, it significantly reduces the resistance of the reheat system. The advanced American AFT fluid calculation software was used to calculate the pressure drop under TMCR working conditions based on the actual situation of the project.

The calculation of the pressure drop in a pipe differs depending on the selected pipe friction model. The effect of pipe friction is considered as part of the full compressible method. In the present study, the Darcy–Weisbach loss model was used to evaluate the effect of the Darcy Friction Factor, the pipe geometry, fluid density, and fluid velocity on the pressure drop in the pipe. The Darcy–Weisbach pressure loss equation for incompressible flow presented as Equation (1) was used to explore this relationship [2]. The Darcy Friction Factor differs from the Fanning Friction Factor by a factor of 4.

$$\Delta P = f \frac{L}{D} \frac{1}{2} \rho V^2 \quad (1)$$

where ΔP represents pressure drop, D indicates pipe diameter, f represents resistance coefficient, L indicates pipeline length, ρ indicates fluid density, and V indicates flow velocity.

This model requires the calculation of a friction factor, accomplished by various methods, for example, the Roughness-Based Method, whereby the friction factor is calculated based on the roughness of the pipe wall. Different equations were used to determine the friction factor based on flow regime. For instance, the laminar flow was evaluated using the standard laminar relationship, whereas the turbulent flow was determined using the implicit Colebrook–White equation. A linearly interpolated value was used in the transition range between the laminar and turbulent flow. The default transition Reynolds numbers can be modified in the system properties, as shown in Equations (2) and (3) [1–3].

$$f = \frac{64}{Re} \text{Laminar, } Re < 2300 \text{ (default)} \quad (2)$$

$$f = \left[1.14 - 2 \log \left(\frac{\epsilon}{D} + \frac{9.35}{Re \sqrt{f}} \right) \right]^{-2} \text{Turbulent, } Re > 4000 \text{ (default)} \quad (3)$$

The parameters were set as follows:

Absolute Roughness (default)—The absolute average roughness height ϵ was directly specified;

Relative Roughness—The roughness was specified as the ϵ / D ratio;

Hydraulically Smooth—The ratio ϵ / D was set to zero;

Explicit Friction Factor—The friction factor used in the Darcy–Weisbach equation was directly specified.

The project is currently in the preliminary design stage and has not been tested in a practical application, so the comparison between the actual measured and calculated values was not conducted. The results calculated using the software are similar to the actual measured values based on previous designs, with a deviation less than 1%. Therefore, the pipe diameter can be optimized and selected according to the software calculation results.

The bend loss correlations were determined for turbulent Reynolds numbers. The k -values for a smooth, flanged bend with $r/D \geq 1$ are presented in Table 1. The size of the bend pipe used in the current project was $r/D = 3$, and that of the normal elbow pipe

was $r/D = 1.5$. A schematic diagram showing the pipe bending radius and diameter is presented in Figure 2.

Table 1. K-values for 90-degree smooth flanged bends.

r/d	K
1	$20 f_T$
1.5	$14 f_T$
2	$12 f_T$
3	$12 f_T$
4	$14 f_T$
6	$17 f_T$
8	$24 f_T$
10	$30 f_T$

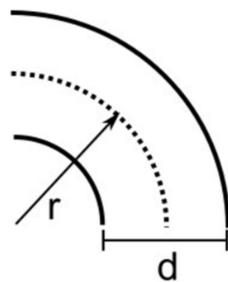


Figure 2. Schematic diagram showing the pipe bending radius and diameter.

The standard threaded elbow pipe was determined as shown in the equation below:

$$K = 30f_T \quad (4)$$

where f_T represents the turbulent friction factor presented in Table 2.

Table 2. Pipe friction factors used for the Crane formulas.

Nominal Size	Friction Factor f_T
1/2"	0.027
3/4"	0.025
1"	0.023
1 1/4"	0.022
1 1/2"	0.021
2"	0.019
2 1/2", 3"	0.018
4"	0.017
5"	0.016
6"	0.015
8–10"	0.014
12–16"	0.013
18–24"	0.012

4. Results

4.1. Technical and Economic Analysis of the Pressure Drop of the Main Steam System

The pipeline resistance was markedly reduced after pipe diameter optimization, layout optimization, and the replacement and optimization of the bend pipe in the main steam system. The results show that the optimized resistance of the main steam pipeline was 0.808 MPa, accounting for 2.61% of the rated pressure of the main steam valve of the steam turbine (Table 3). This indicates that maintaining the rated pressure of the main steam valve of the steam turbine at a constant level can reduce the outlet pressure of the

boiler superheater and the outlet pressure of the feed pump, as well as reducing the energy consumption of the feed pump. The results of the calculations for the resistance of the main steam pipe specification $ID343 \times 119$ + bend pipe are shown in Figure 3.

Table 3. Optimization results of the main steam pipeline resistance (two units).

Main Steam Pipe Specification	ID339 × 116	ID349 × 122	ID343 × 119	ID343 × 119
Use of elbow or bend pipe	Elbow	Elbow	Elbow	Bend pipe
Temperature (°C)	615	615	615	615
Superheater pressure (MPa)	31.871	31.753	31.822	31.808
Inlet pressure of the main steam valve of steam turbine (MPa)	31	31	31	31
Pressure loss ratio	2.81%	2.43%	2.65%	2.61%
Heat consumption increment (KJ/kWh)	Benchmark	−1.18	−0.49	−0.63
Increment of coal consumption data (g/kWh)	Benchmark	−0.046	−0.019	−0.024
Annual coal cost increment (CNY Ten thousand)	Benchmark	−37.35	−15.51	−19.94
Pipe weight increment (t)	Benchmark	62.64	29.16	29.16
Initial investment increment of pipeline (CNY Ten thousand)	Benchmark	444.52	206.93	206.93
20-year income determined by cost present value method (CNY Ten thousand)	Benchmark	428.35	177.88	228.70
Total income in 20 years (CNY Ten thousand)	Benchmark	−16.17	−29.05	21.77

Note: the rated output of the unit at the time the study was conducted was 1000 MW, the number of hours for power generation was 5000 h, the standard coal price was 817 CNY/T, and the 20-year discount factor was 11.47.

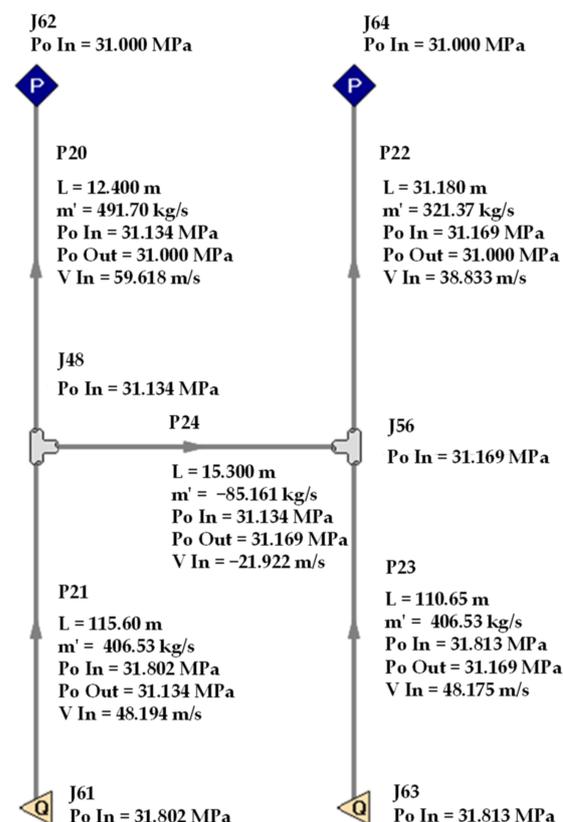


Figure 3. Results of the resistance of the $ID343 \times 119$ + bend pipe used as the main steam pipe.

The resistance calculation results of the main steam pipeline are presented in Table 3. The $ID343 \times 119$ specification was selected for the main steam pipe after analyses, and the elbow technology was adopted.

4.2. Technical and Economic Analysis of the Pressure Drop of Primary Reheat Steam System

The pipeline resistance significantly reduced after the optimization of the pipe diameter, layout optimization as well as the replacement and optimization of the bend pipe for the primary reheat system. The findings show that a decrease in the pressure of the entire system of the primary reheat system accounted for 4.88% of the pressure at the ultra-high-pressure exhaust port, which was 0.6445 MPa (Table 1). The resistance results of the ID438×81 + bend pipe are presented in Figure 4. The calculated resistance results of the ID851×97 primary cooling pipe are presented in Figure 5.

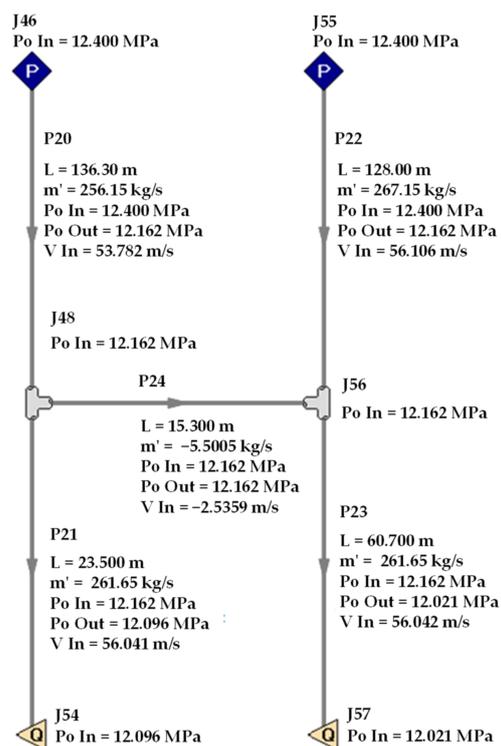


Figure 4. Results of the resistance of the optimized ID438 × 81 + bend pipe.

Moreover, the primary heat pipe utilized the elbow technology. The diameter of the primary cold pipe was increased. The final specifications were: primary heat pipe was ID438×81 and primary cold pipe was ID851 × 97. The optimization of the entire primary reheat system led to a pressure drop of 4.88%, which has higher economic benefits compared with the conventional pressure drop of 6.62% (Table 4).

Table 4. Optimization results of the pipeline resistance of the primary reheat system (two units).

Primary Heat Pipe Specifications	ID419 × 78 Using the Elbow Pipe	ID438 × 81 Using the Bend Pipe
Primary cooling pipe specification	ID845 × 94	ID851 × 97
Pressure loss of the high pressure reheater	1.5%	1.5%
Total pressure drop of the primary reheat pipeline (MPa)	0.874	0.6445
Total pressure loss of the primary reheat system	6.62%	4.88%
Heat consumption increment (KJ/kWh)	Benchmark	−7.13
Increment of coal consumption (g/kWh)	Benchmark	−0.276
Annual coal cost increment (CNY Ten thousand)	Benchmark	−225.67
Initial investment increment of the pipeline (CNY Ten thousand)	Benchmark	501.29
20-year income determined by cost present value method (CNY Ten thousand)	Benchmark	2588.49
Total income in 20 years (CNY Ten thousand)	Benchmark	2087.20

Note: the rated output of the unit during the time of the study was 1000 MW, the number of hours for power generation was 5000 h, the standard coal price was 817 CNY/T, and the 20-year discount factor was 11.47.

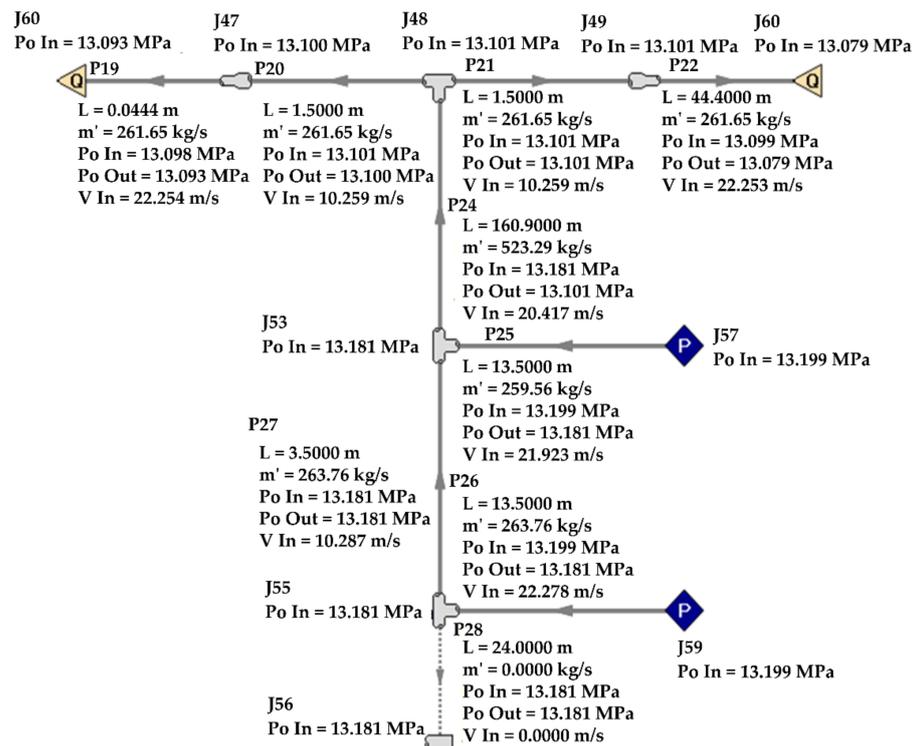


Figure 5. Results of the resistance of the primary cooling pipe specification ID851 × 97.

4.3. Technical and Economic Analysis of the Pressure Drop of the Secondary Reheat Steam System

The pipeline resistance was significantly reduced after the optimization of the pipe diameter, layout optimization as well as the replacement and optimization of the bend pipe of the secondary reheat system. The findings show that the pressure drop of the secondary reheat system in the entire system accounted for 8.13% of the pressure at the high-pressure exhaust port, which was 0.312 MPa (Table 2). The calculated secondary heat pipe specification results for the ID870 × 44 + elbow pipe resistance are presented in Figure 6. The calculated resistance results of the secondary cooling pipe Ø1219 × 34.9 are shown in Figure 7.

The elbow technology was also adopted for the secondary heat pipes. The diameter of the secondary cooling pipe was increased. The final specifications were: ID870 × 44 for the secondary heat pipe and Ø1219 × 34.9 secondary cooling pipe. The pressure drop optimization of the entire secondary reheat system was 8.13%, which was economically better compared with the conventional pressure drop of 9.53% (Table 5).

Table 5. Optimization results of the pipeline resistance of the secondary reheat system (two units).

Specifications of the Secondary Heat Pipe	ID851 × 41 Using the Elbow Pipe	ID870 × 44 Using the Bend Pipe
Specification of the secondary cooling pipe	Ø1168 × 31.8	Ø1219 × 34.9
Pressure loss of the low pressure reheater	5.2%	5.2%
Total pressure drop of the secondary reheat pipeline (MPa)	0.366	0.312
Total pressure loss of the secondary reheat system	9.53%	8.13%
Heat consumption increment (KJ/kWh)	Benchmark	−7.86
Increment of coal consumption (g/kWh)	Benchmark	−0.304
Annual coal cost increment (CNY Ten thousand)	Benchmark	−248.64
Initial investment increment of the pipeline (CNY Ten thousand)	Benchmark	579.55
20-year income evaluated by the cost present value method (CNY Ten thousand)	Benchmark	2851.87
Total income in 20 years (CNY Ten thousand)	Benchmark	2272.32

Note: the rated output of the unit at the time of the study was 1000 MW, the utilization hours of power generation was 5000 h, the standard coal price was 817 CNY/T, and the 20-year discount factor was 11.47.

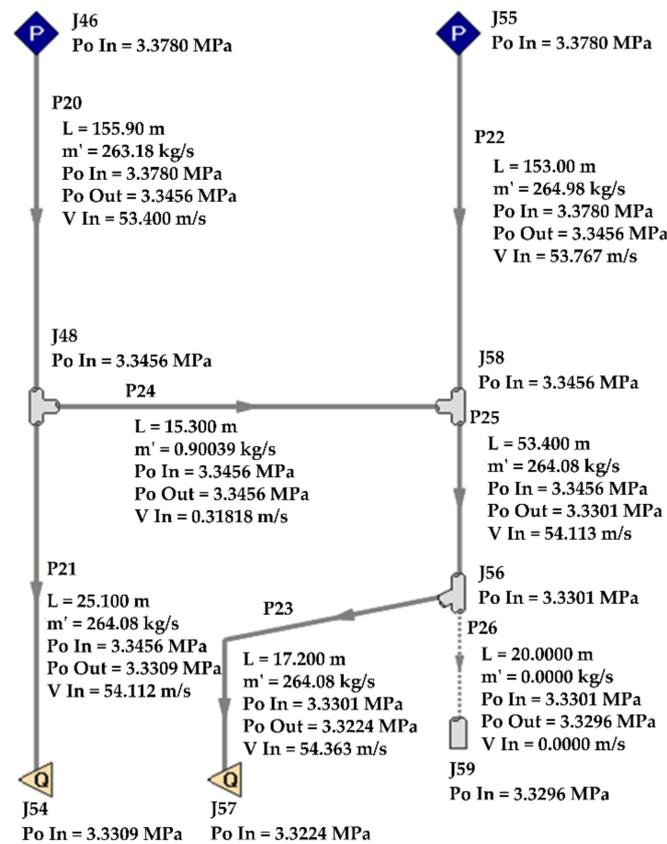


Figure 6. Results of the resistance of the secondary heat pipe ID870 × 44 + bend pipe.

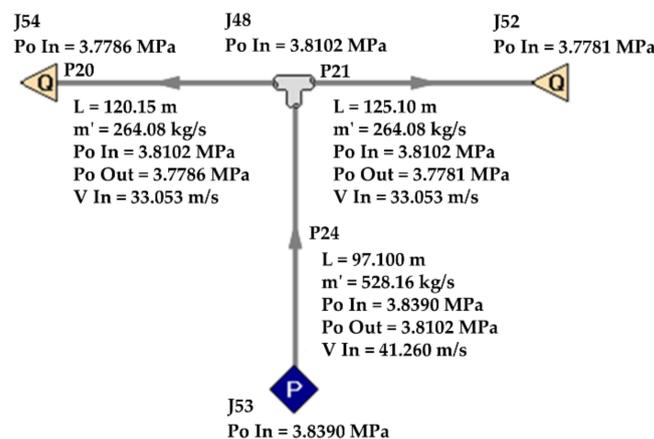


Figure 7. Results of the resistance of the secondary cooling pipe $\varnothing 1219 \times 34.9$.

4.4. Discussion

The thermal system of the ultra-supercritical 1000 MW secondary reheat unit uses a two-stage reheat system to improve the thermal effectiveness of the unit. Increasing the inlet pressure of the main steam and reheated steam, under the same other boundary conditions, reduces the heat consumption rate of the steam turbine. Methods for increasing steam turbine inlet pressure include raising the feed pump head and reducing the medium flow resistance. Raising the feed pump head consumes pump drive energy, whereas reducing the medium flow resistance mainly saves part of the resistance that is consumed. Increasing the flow area of the pipeline, for a pipeline with the same pressure and temperature grade, involves increasing the thickness of the pipeline wall and correspondingly increasing the

initial amount of pipeline materials. The benefits resulting from reducing the pressure loss outweigh the limitations, when the initial investment increases to a certain extent, so it is important to determine the optimal parameters for the thermal system. Therefore, the present study sought to explore the optimal parameters for minimizing the pressure drop and reducing the cost of operation. The findings indicate that the optimization of pressure drop results in a significant reduction in the heat consumption of the steam turbine, the minimization of coal consumption, and, ultimately, the increase in the total income. Moreover, the optimization of the primary heat system decreases the steam turbine consumption and markedly decreases the standard coal consumption, thus significantly minimizing production costs and eventually increasing the total income. Furthermore, the optimization of the secondary reheat system decreased the total coal consumption and reduced steam turbine heat consumption, thus minimizing production costs, which ultimately increases the total income. Previous findings indicate that an increase in the pipe diameter in steam systems lowers the hydraulic resistance and heat flux. The effect of using the bend pipe technology was evaluated in the current study. The results show that the cost of the cold pipeline section was lower compared with that of the hot pipeline section. These findings indicate that an increase in pipe diameter does not significantly increase the operation costs. Notably, an increase in pipe diameter markedly decreases the resistance of the reheat system, which is consistent with previous findings. Moreover, the replacement of the conventional pipe with the bend pipe and the layout optimization significantly reduced the pipeline resistance. These findings imply that maintaining a constant optimal pressure in the main system valve decreases the outlet pressure of the feed pump and the outlet pressure of the boiler superheater, as well as minimizing energy consumption by the feed pump.

In addition, the replacement of the normal pipe of the primary reheat system with a bend pipe and the optimization of the pipe diameter markedly reduced the pipeline resistance. The optimization of the primary reheat system led to a significant pressure drop relative to the conventional pressure drop, ultimately reducing the cost of operation. Furthermore, the use and optimization of a simmer bend pipe as well as the layout optimization of the secondary heat system markedly reduced the pipeline resistance. All these strategies reduce the cost of operation of the system, ultimately increasing the total income.

The diameter and length of the ultra-high-pressure cylinder are normally small, and the interface thrust of the main steam pipe and the cold primary reheat steam pipe that it can withstand is small owing to the small expansion pressure ratio and enthalpy drop of the ultra-high-pressure cylinder of the secondary reheat unit. Notably, the wall thickness of the main steam pipe significantly increases with the increase in the main steam pressure, and the exhaust steam temperature also increases. The flow rate of the cold primary reheat steam pipe is reduced, and the pipe diameter is increased to reduce the resistance of the reheat system and improve the thermal efficacy of the unit. Moreover, the distance between the machine and the furnace is reduced to shorten the length of the main steam pipe and reheat steam pipe and reduce the cost and the resistance of the steam pipe. This implies that reducing the thrust and torque of the main steam valve interface and the exhaust interface of the ultra-high-pressure cylinder is the main challenge when designing the main steam pipeline and the primary cooling and reheating steam pipeline. Similarly, it is relatively challenging to reduce the thrust and torque of the reheat steam valve interface and the exhaust steam interface of the high-pressure cylinder. The optimization of pipe parameters in the primary and secondary reheat systems markedly reduced the pipeline resistance in the present study, thus improving the pressure drop, which minimizes the cost of operation of the main steam system. The findings of the present study provide a basis for further optimizing the main steam system to reduce the costs incurred during operation, thus maximizing the total income of thermal power plants. Further studies should be conducted to explore the field application of these parameters and evaluate their effects on production costs in thermal power plants.

5. Conclusions

The findings from the present study indicate the following:

(1) The pressure drop of the main steam pipeline was 0.808 MPa, after optimizing the design parameters to minimize the pressure drop under TMCR working conditions, which is 2.61% of the rated inlet pressure of the steam turbine (31 MPa (a)). The pressure drop of the primary reheat system of the project was 0.6445 MPa, which is 4.88% of the exhaust pressure of the ultra-high-pressure cylinder of the steam turbine (13.199 MPa (a)). Furthermore, the pressure drop of the secondary reheat system was 0.312 MPa, which is 8.13% of the exhaust pressure of the high-pressure cylinder of the steam turbine (3.839 MPa (a)). These findings indicate that all the requirements of the technical design code of large- and medium-sized thermal power plants were met.

(2) The results of the present study indicate that the main steam pipeline and reheat hot section pipeline should adopt the scheme of a simmer bend pipe, which reduces the unit operation cost, improves the unit efficiency of the power plant, and ensures energy savings, as well as guaranteeing the safe operation of the pipelines.

(3) The specifications of the main steam pipeline, reheat hot section pipeline, and reheat cold section pipeline achieved after the optimization of the project met the requirements for an effective system and minimizes the cost of establishing the unit. The pressure loss of the main steam pipeline was optimized to 2.61%, the heat consumption of the steam turbine was reduced by about 0.63 kJ/(kW·h), the standard coal consumption decreased by about 0.024 g/(kW·h), and the total income in 20 years from the project is projected to be approximately CNY 217,700. The primary reheat system was increased to 4.88%, the steam turbine heat consumption was reduced by about 7.13 kJ/(kW·h), the standard coal consumption was minimized by about 0.276 g/(kW·h), and the total income in 20 years is projected to be approximately CNY 20.872 million after the optimization of the total pressure drop. The secondary reheat system was increased to 8.13%, the steam turbine heat consumption was reduced by about 7.86 kJ/(kW·h), the standard coal consumption was reduced by about 0.304 g/(kW·h), and the total income in 20 years is projected to be approximately CNY 22.7232 million after the optimization of the total pressure drop.

The research results provide a basis for the further optimization of the design and operation of secondary reheat units, which significantly increase the income and ensure the safe operation of the unit.

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