ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

Strength Analysis of Outlet Header Structure of Evaporator of Waste Heat Boiler in Cement Kiln

Jingan Lai, Qingzhong He, Bitong Zhao, Kehong Li, Rundong He, Chao Zuo

School of Mechanical Engineering Sichuan University of Science & Engineering in China, 644000, Sichuan China.

Abstract

Based on the discrete element theory and the ANSYS thermodynamic coupling module, the structural strength of the outlet header of the cement kiln waste heat boiler evaporator is analyzed. The results show that: the maximum thermal stress and maximum thermal strain of the evaporator outlet header appear at the junction of the header box and the large pipeline, the maximum thermal stress value is 4.65 MPa, and the maximum thermal strain value is 2.19×10-5 mm; The maximum coupling stress occurs at the junction of the header box and the large pipeline, and the header box and the small pipeline. The primary membrane stress of the header box is 119.86 MPa, the primary membrane stress of the large pipeline is 115.01 MPa, and the primary membrane stress of the small pipeline. It is 116.51 MPa, and the primary film stress + bending stress + secondary stress are 136.88 MPa, 129.71 MPa, and 183.86 MPa, respectively.

Keywords

Cement Kiln; Waste Heat Boiler; Evaporator; Header; Structural Strength Analysis.

1. Introduction

Waste heat power generation is a technology that uses excess heat energy in the production process to convert into electrical energy. Waste heat power generation is not only energy saving, but also conducive to environmental protection. It is an important technology for the country to implement energy saving and emission reduction [1-4]. In recent decades, the cement industry has undergone many changes, its production technology and equipment have been continuously improved, and the output has been increasing year by year. At present, the global cement production is about 4 billion tons, and it is estimated that by 2050, the global cement production will exceed 5 billion tons [5-8]. A certain company’s cement kiln production line is equipped with a waste heat boiler at the kiln head and a set of low-parameter mixed-pressure pure condensing steam turbine generator sets to make full use of the waste heat from process production and achieve the purpose of saving energy and reducing energy consumption.

The evaporator of the cement kiln waste heat boiler is prone to corrosion or even failure during the long-term standby period of the unit, which brings serious safety hazards to the unit itself, which will have a certain impact on the economic benefits of the power plant. Through analyzing and researching the failure problem, and formulating relevant countermeasures, the safe and stable operation of the waste heat boiler and the unit is guaranteed [9-12].

Domestic scholars have mainly conducted research on waste heat recovery and denitrification technology of waste heat boilers. Li Senlin [13] analyzed the relationship between the heating value of self-used steam and boiler load, and concluded that recovering the heat in exhaust gas will further improve the comprehensive utilization rate of natural gas and reduce carbon dioxide emissions. Du

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

Long [14] used a variety of methods to calculate the acid dew point temperature of the exhaust gas of a waste heat boiler in a gas-steam combined cycle unit, and summarized a set of calculation methods to reduce the exhaust gas temperature of the waste heat boiler. Ma Jinwei [15] tested and analyzed the corrosion of the heat exchange tube of the waste heat boiler, and concluded that the corrosion failure of the heat exchange tube of the boiler was the result of the combined effect of sulfuric acid dew point corrosion and sulfate. Lv Qinghuan [16] analyzed the causes of failure and proposed protective measures for the furnace tube in view of the local corrosion and perforation leakage of the waste heat boiler tube. Liu Xianliang [17] conducted a sampling test on the cracked elbow of the heating surface of the low-pressure superheater, analyzed the cause of the crack, and found that the crack was caused by the combined action of residual stress, thermal stress during operation, and working load stress. However, there is little research on the evaporator inside the boiler.

2. Main parameters and 3D model

2.1 Design parameters

The main design parameters of the evaporator header of the cement kiln head waste heat boiler are shown in Tab. 1.

Tab. 1 Main design parameters of evaporator header

Design parameter	size	unit
Hydraulic test pressure	2.25	MPa
Working pressure	1.5	MPa
Calculated pressure	2	MPa
Calculated temperature	240	°
Working medium water	vapor	
Body material	20 20cr Q245R	

2.2 Material parameters

The mechanical properties of the selected materials are shown in Tab. 2:

Tab. 2 Material mechanical performance parameters

Material designation	20	20cr	Q245R
Density(Kg/m^3)	7.8×10^3	7.8×10^3	7.8×10^3
Modulus of Elasticity (GPa)	213	211	211
Poisson's ratio	0.282	0.286	0.286
Thermal conductivity (m•°C)	45	48	48
Specific heat capacity (J/Kg•°C)	485	440	440
Allowable stress (MPa)	110	110	110
Average linear expansion system($°C^{-1}$)	11.92×10^{-6}	1.24×10^{-5}	1.24×10^{-5}

2.3 Three-dimensional model

According to the drawings of the outlet header of the evaporator of the 5000t/d cement kiln waste heat boiler evaporator, the 3D modeling software SolidWorks is used to establish a 3D solid model, and features such as chamfers and round holes that have little effect on the result are ignored when modeling; parts such as seal rings and springs It has little effect on the structural strength analysis results, and it is ignored; at the same time, in order to obtain more accurate analysis and calculation results, increase the length of the pipe diameter by 10 times (to avoid stress singularity), and the established three-dimensional solid model is shown in Fig. 1.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

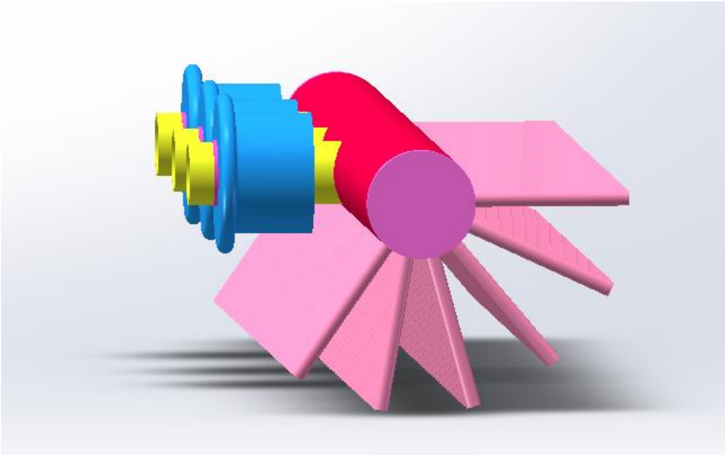


Fig. 1 Three-dimensional model

3. Analysis of stress and deformation of boiler evaporator outlet header

3.1 Meshing model

The three-dimensional solid model of the outlet header of the cement kiln waste heat boiler evaporator is divided into small units according to certain rules. The units are connected by nodes, and loads can be transferred between the nodes. The sum of these units is called the finite element model. The establishment of finite element model is also called meshing.

If the three-dimensional model of the outlet header structure of the cement kiln waste heat boiler evaporator only changes the size parameters in the mesh setting, the small size structure may be ignored when the one-click method is used to divide the grid, which makes the analysis and calculation results inaccurate. When meshing small pipes, because the size of the structure is relatively small, if the size of the mesh is matched with the whole, the quality of this part of the mesh will be very poor, and the result will be too large error in subsequent calculations . Therefore, when meshing the outlet header model of the cement kiln waste heat boiler evaporator, first use the same mesh size to divide the mathematical model, and then subdivide the mesh at the small or critical section, such as: small For pipes and headers, the section of small pipes is divided into 2 parts by using surface mesh, and the cross section of header is divided by sweep and surface mesh, and the mesh size is 2 equal parts. The finite element model of the outlet header of the waste heat boiler evaporator is obtained by dividing the grid in the above manner, with a total of 3820286 nodes and 701639 units, as shown in Fig. 2.

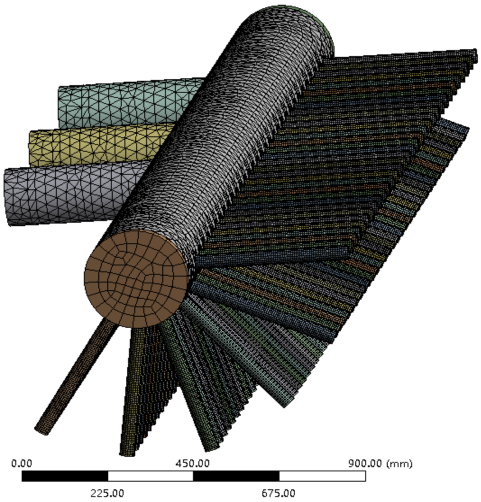


Fig. 2 Meshing model

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

3.2 Boundary condition setting

Boundary conditions include constraint conditions and load conditions. Constraints are imposed according to actual working conditions, as shown in Figures 3 and 4; fixed constraints are imposed on the large pipe and small pipe section at the outlet header of the waste heat boiler evaporator. According to the actual working conditions, apply the corresponding load, apply a pressure of 2MPa inside all the pipes, and apply a temperature load to the inner pipes at the same time, as shown in Fig. 5, Fig. 6, Fig. 7, Fig. 8.

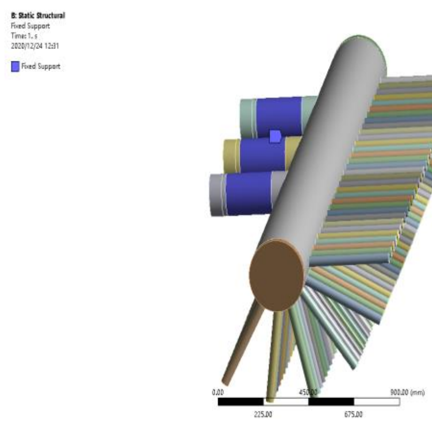


Fig. 3 Constraints on the surface of a large pipe

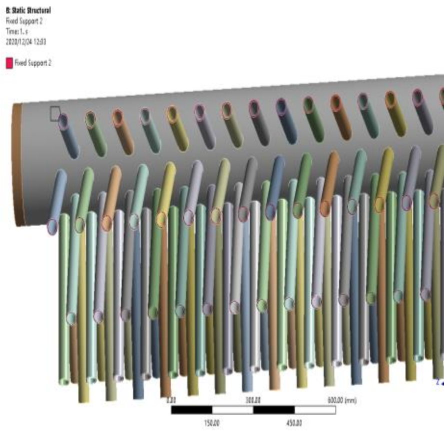


Fig. 4 Restriction imposed on a small pipe section

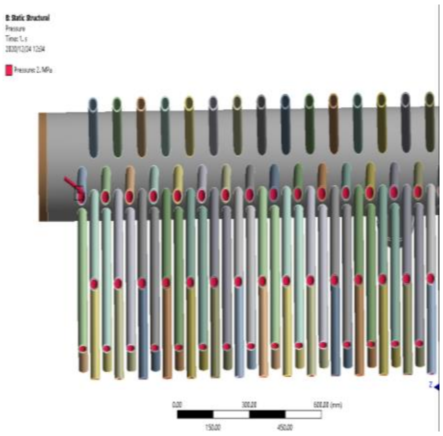


Fig. 5 Applying 2MPa pressure inside the small pipe

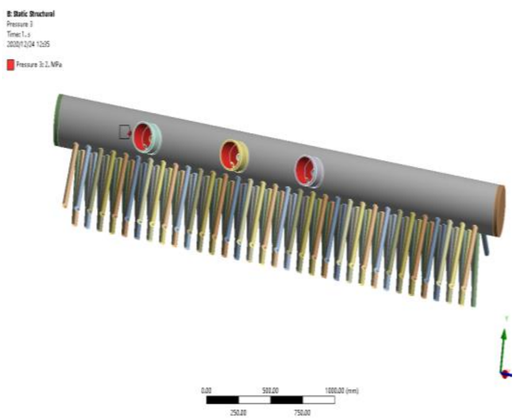


Fig. 6 2MPa pressure is applied inside the pipeline

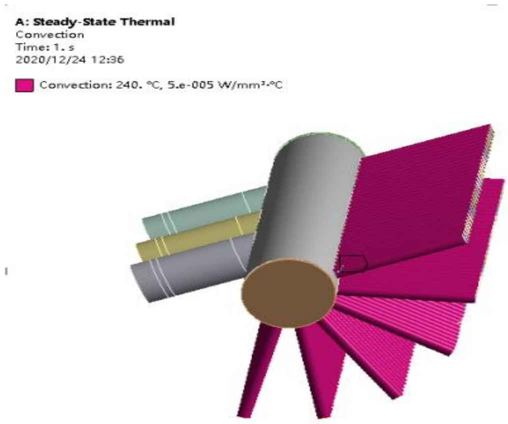


Fig. 7 Temperature load applied to external pipeline

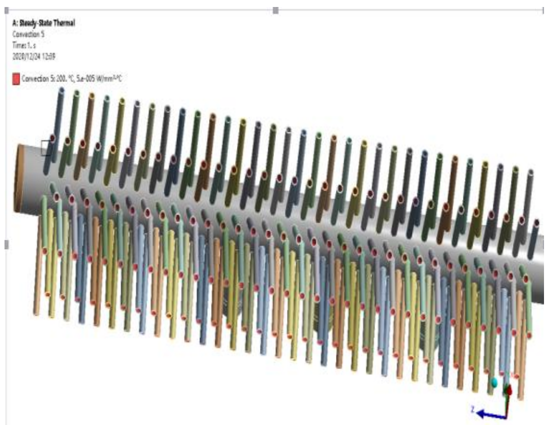
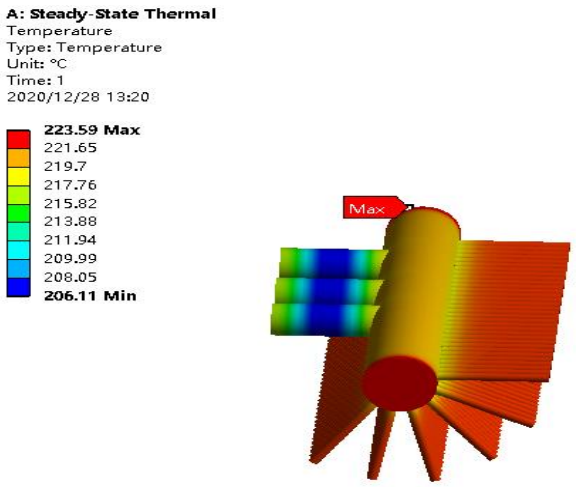
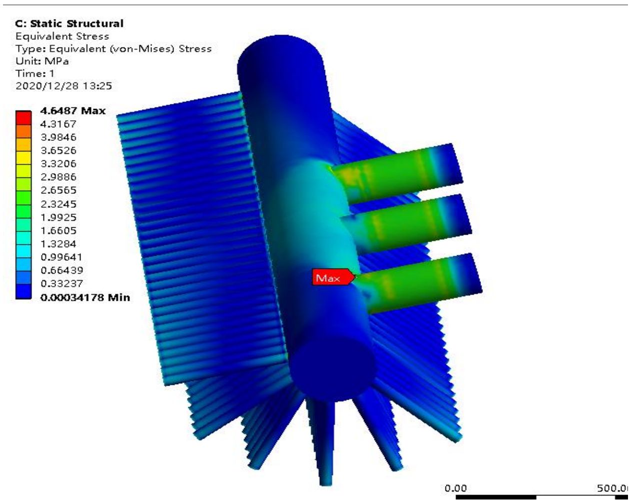


Fig. 8 Temperature load applied to the internal pipeline

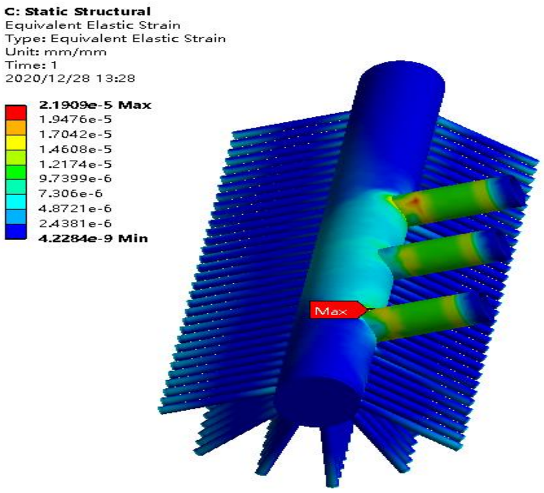
ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014



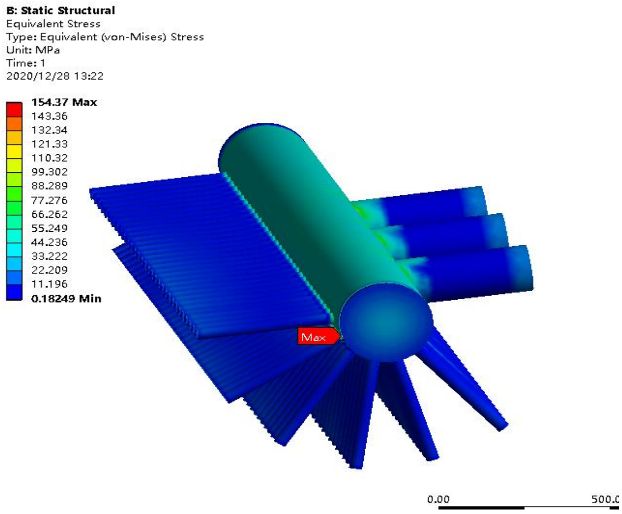
(a) Overall temperature field distribution



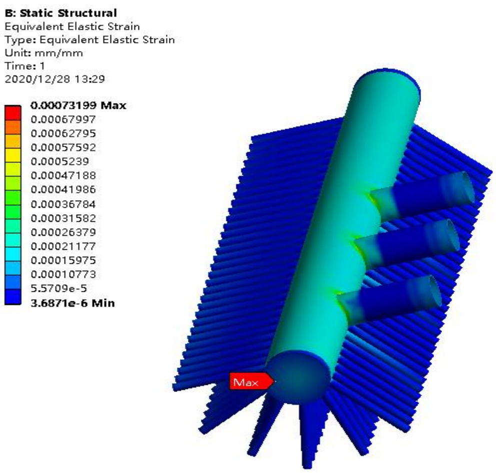
(b) Equivalent stress of temperature field



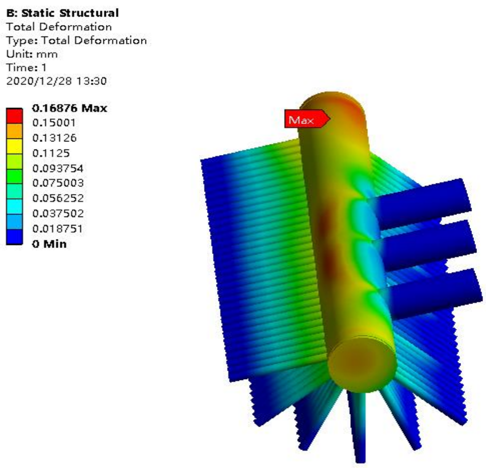
(c) Equivalent strain of temperature field



(d) Overall equivalent stress distribution diagram



(e) Overall equivalent strain diagram



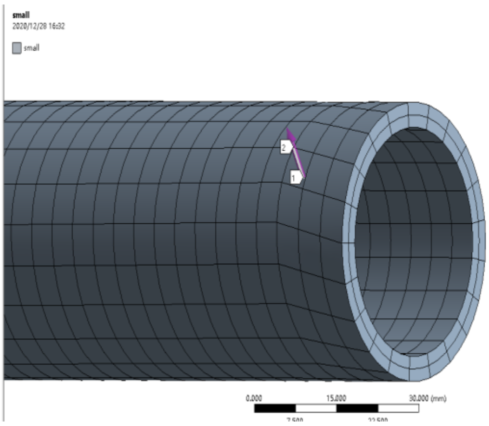
(f) Overall equivalent deformation diagram

Fig. 9 Calculation results

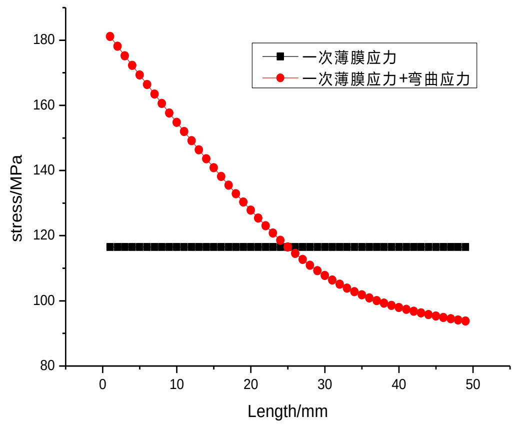
ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

3.3 Analysis of calculation results

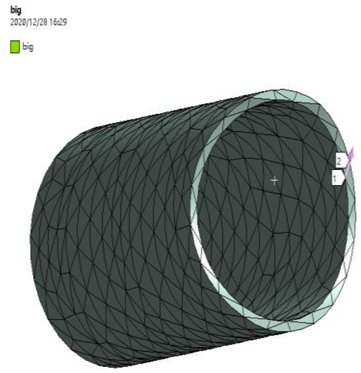
After meshing, material property definition, constrained boundary conditions and related geometric processing, the ANSYS software analysis and calculation module (solver) is used to perform finite element structural stress and strain analysis and calculation, and the post-processing module is used to check and summarize the output calculation results , Get the equivalent stress, stress intensity, deformation, etc. of the outlet header of the waste heat boiler evaporator, the results are shown in Fig. 9, (a), (b), (c), (d), (e), (f) They are the overall temperature field, the equivalent stress of the temperature field, the equivalent strain of the temperature field, the overall equivalent stress distribution diagram, the overall equivalent strain diagram, and the overall equivalent deformation diagram.



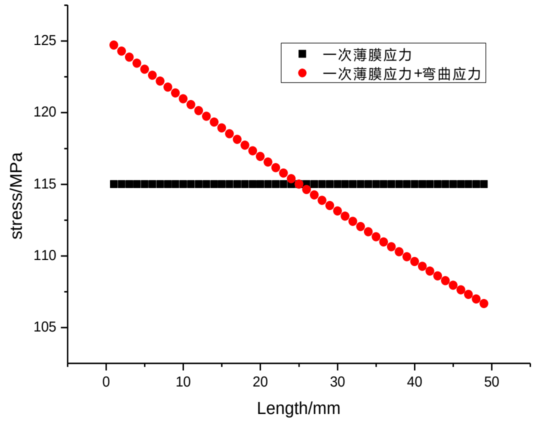
(a) Small pipeline stress linearization path



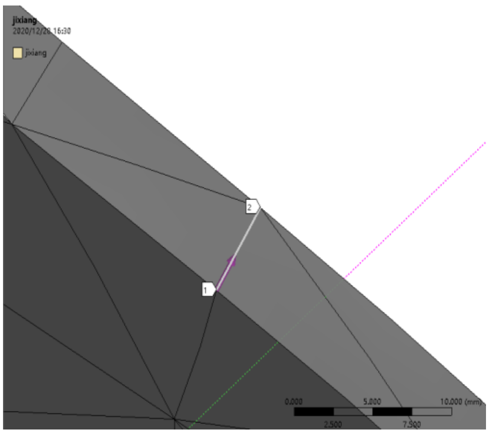
(b) Small pipe stress linearization results



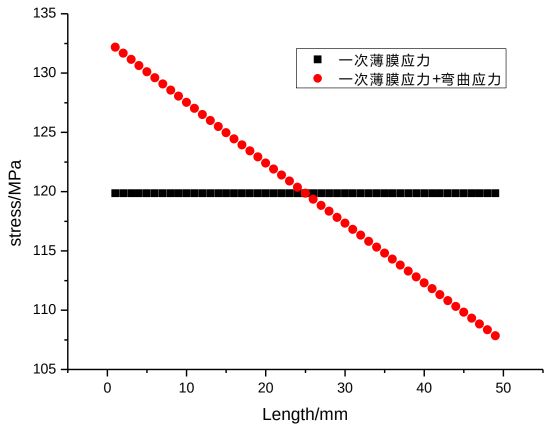
(c) Large pipeline stress linearization path



(d) Large pipe stress linear results



(e) Header box stress linearization path



(f) Header box linearized stress results

Fig. 10 Stress linearization results

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

3.4 Stress linearization analysis

It can be seen from Fig. 9 that the maximum stress is mainly concentrated at the connection position of the header and the small pipeline. The evaluation is carried out in accordance with the requirements of JB 4732-2005《Steel Pressure Vessels-Analysis and Design Standards》. The function classifies the stress into primary stress, secondary stress, and peak stress, and compares them with the given stress intensity. The requirement for a qualified design is that the actual stress intensity does not exceed their allowable value. The evaluation methods of stress intensity are divided into point treatment method and line treatment method. This operation selects the line treatment method, which is to find the maximum structural stress according to the third strength theory, and then establish a stress linearization path along the wall thickness direction through this point, and then decompose the stress into film stress and bending stress along the path, and finally follow the Related standards are evaluated, as shown in Tab.3.

Tab. 3 Check of various types of stress intensity

Type	Calculation formula	Limit value
Primary film stress	Pm	S_m
Primary film stress + bending stress + secondary stress P_m+P_b+Q 3Sm	P_m+P_b+Q	$3S_m$

It can be seen from Fig. 9 that the maximum stress occurs at the junction of the header box and the small pipe, and the stress linearization path is established along the wall thickness direction through this point, so that the linearization results of primary film stress, primary film stress + primary bending stress are obtained as follows: As shown in Fig. 10.

4. Conclusion

(1) Through the thermal coupling of ANSYS, it is found that the maximum stress of the outlet header of the cement kiln waste heat boiler evaporator appears at the connection between the large pipe and the header box, the connection between the small pipe and the header box, and the end cover and the box. At the connection, the maximum primary film stress of the small pipe is 116.51 MPa, the primary film stress + bending stress + secondary stress is 183.86 MPa; the maximum primary film stress of the large pipe is 115.01 MPa, and the primary film stress + bending stress + secondary stress is 129.71 MPa; the maximum stress of the primary membrane of the header box is 119.86MPa, and the primary membrane stress+bending stress+secondary stress is 136.88MPa.

(2) A three-dimensional model was established based on the drawings provided by a company, and the structural stress-strain characteristics of the evaporator outlet header were calculated using the finite element analysis method. According to the pressure vessel calculation criteria, the above calculated parts were checked according to the third strength theory: The primary local membrane stress of the small pipe is 116.51MPa, and the surrounding stress is evenly distributed, which is less than 1.5 times the allowable yield stress. The primary membrane stress + bending stress + secondary stress of the small pipe is 183.86 MPa, which is less than 3 times the allowable yield stress. The structure is safe. The primary local membrane stress of the large pipeline is 115.01MPa, and the surrounding stress is evenly distributed, which is less than 1.5 times the allowable yield stress. The primary membrane stress + bending stress + secondary stress of the large pipeline is 129.71 MPa, which is less than 3 times the allowable yield stress. The structure is safe. The primary local membrane stress of the header pipe is 119.86MPa, and the surrounding stress is evenly distributed, which is less than 1.5 times the allowable yield stress. The primary membrane stress + bending stress + secondary stress of the header box is 136.88MPa, which is less than 3 times the allowable yield stress. Yield stress, structural safety.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202106_7(6).0014

References

[1] LIU Yong-ming. Utilization of low temperature waste gas from AQC waste heat boiler at cement kiln head [J]. Building materials technology and application, 2020 (01): 29-30.

[2] CHEN Jiang-long. Vibration analysis of waste heat boiler water heater at cement kiln head [J]. China special equipment safety, 2020,36 (04): 70-72.

[3] XIAO Yong, WEI Hai-jun. Solutions to low temperature corrosion of economizer at kiln end of cement waste heat boiler [J]. Decision making exploration (middle), 2019 (08): 66-67.

[4] XIAO Yong, WEI Hai-jun. Cause analysis and solution of ash deposition in common superheater of cement waste heat boiler [J]. Metallurgical management, 2019 (11): 55-56.

[5] WU Zhong-jing. Common problems and measures of pure low temperature waste heat boiler for cement kiln [J]. Science and technology wind, 2019 (16): 179.

[6] HUANG Gao-quan. Feasibility study on Transformation of AQC waste heat boiler for cement waste heat power generation [J]. Cement engineering, 2019 (02): 7-11 + 16.

[7] LI Gao-song, ZHANG Zhi-qi. Application example of technical transformation of rapping device of waste heat power generation boiler in cement kiln [J]. Cement, 2018 (12): 64-65.

[8] JIN zhou,WU Cai-li. Operation method of cement kiln waste heat boiler for anti freezing and shutdown [J]. China Hi tech, 2018 (18): 41-43.

[9] LIU Xiao-yu. Simulation study on ash deposition characteristics of superheater tube bundle of SP waste heat boiler in cement kiln [D]. Xiangtan University, 2018.

[10] LI Xiao-qi. Comparison of numerical calculation for settler of two cement kilns [J]. China cement, 2018 (05): 91-92.

[11] HUANG Gao-quan, Peng Yan. Resistance analysis of water supply network of waste heat boiler for cement waste heat power generation [J]. Mining machinery, 2017,45 (06): 68-71.

[12] FANG Yun-long. Research on design and structure optimization of cement kiln waste heat boiler [D]. Anhui University of technology, 2017.

[13] LI Seng-lin. study on the construction of waste heat recovery process of gas boiler exhaust in South thermal power plant [j]. Low carbon world, 2021,11 (02): 3-5.

[14] DU long, SU Yin-ping, REN Nian-mao. Calculation of dew point temperature of exhaust nicotinic acid from waste heat boiler of gas turbine [J]. Electric Power Survey and design, 2021 (02): 46-51.

[15] MA Jin-wei, GU Xiao-hong, ZHANG Yan-feng, et al. Dew point corrosion and protection measures of waste heat boiler of Claus tail gas incinerator [J]. Corrosion and protection of petrochemical industry, 2021, 38 (01): 10-13.

[16] LU Qing-huan,MA Jin-wei,CHEN Shaofan,et al . Failure analysis and protection suggestions for waste heat boiler tubes of tail gas incineration in sulfur recovery unit [J]. Petrochemical equipment, 2021,50 (02): 68-71.

[17] LIU Xian-liang, LAI Yun-ting, YU Min, et al.. Cause analysis on cracking of superheater tube elbow of waste heat power generation boiler [J]. Electric power technology and environmental protection, 2021,37 (01): 57-60.