Research Article
Stress Analysis and Research of a Cyclone in CAGG Units

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Abstract: The cyclone is one of the key equipment in the high-pressure (2.0~3.0 MPa) Coal Ash-Agglomerated Gasification (CAGG) units. Based on the stress classification method and the design-by-analysis rule, using numerical simulation and ANSYS software, calculation and analysis have been carried out on a cyclone which has rectangular vortex inlet and flat head. The comparative studies have been made for those which have different quantities of stiffened plates. Conclusion can be drawn that the application of stiffened plates is a good option to improve top head stress distribution.

Keywords: CAGG unit, cyclone, design-by-analysis, numerical simulation, stress distribution

INTRODUCTION

Coal gasification is a technology of producing gas fuels and gas materials ($CO+H_2$) by using solid coals. CAGG is a new-developed gasification process. In this process, the pulverized coal will be gasified in an ash-agglomerated fluidized bed gasifier.

Nowadays, the operating pressure is about 0.2~0.6 MPa in the industrial application of CAGG units. To meet higher capacity requirements of future commercial units, it is essential that the operating pressure must be raised to a higher pressure of 2.0~3.0 MPa. For a same size gasifier, the capacity can raise from 200~300 tons/day to 1000~1500 tons/day after raising the operating pressure. The cyclone is one of the key equipment in the higher-pressure CAGG units. The traditional typical cyclone has the structure of rectangular vortex inlet and flat head. Those structures are not reasonable for good stress distribution from the opinion of pressure design. Normally, the flat head should be used while the vessel diameter is small (less than 500 mm) and the operating pressure is low (less than 1.0 MPa). In the future higher-pressure CAGG units, the cyclone diameter will be larger up to 2000 mm. The operating pressure will be higher up to 3.0 MPa and the operating temperature will be 1100 °C. Evidently, the engineering design of high-pressure and high-temperature cyclone is an inevitable challenging work.

To deal with the issues of the traditional cyclone, Sun *et al*. (2006) put forward a new-type cyclone with vault top, eccentric vortex finder and straight cut-in round inlet. The stress distribution of new-type cyclones is improved to some extends. On the other hand, the refractory lining installation will be a more difficult thing. It is also a big problem that different thickness lining will cause different temperature distribution. In fact, it is difficult to remain the same separation efficiency for the new-type cyclone compare with the traditional cyclone.

On the base of remaining the traditional structure, the cyclone dimensions are optimized according to the media properties and the operating conditions in CAGG units. It is essential to ensure the excellent separation performance. Secondly, the cyclone stress distribution is also optimized by using stiffened plates. The new-developed cyclone with stiffened plates will meet the high-pressure requirements. Because of remaining rectangular vortex inlet and flat head, the keeping simple structures make it easy to manufacture metal shells and install refractory.

Cyclones are thin-walled pressure vessels and have similar structure with the conjunction of thin flat cover and thin cylindrical shell. What's more, the rectangular vortex inlet makes the top head structure more complex and the stress distribution worse. For a single thin-walled element, membrane shell theory can be used for stress analysis. Large shear stress and large bend moment caused by interactive constraints will appear in the flat cover and cylindrical shell conjunction component. Especially the boundary stress is huge. Membrane shell theory is inapplicable in such a condition. Additional bending moment and additional shear stress can be soluble by using plate-shell elastic mechanics theory and related simultaneous equation (Wang, 2011). Although are usually used in the industrial applications, many methods of design-by-rules are not accurate enough and not suitable for the flat head (ASME, 2010a; Dennis, 2004; Farr and Jawad, 2010; Warren and Richard, 2011). Furthermore,

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Table 1: Dimensions of components used in the numerical simulations

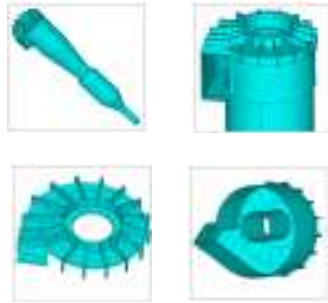| Components	Outlet pipe	Stiffened plate	Top cover	Inlet channel	Bottom plate	Shell
Thickness (mm)	42	42	42	42	42	42

Fig. 1: Cyclone geometrical model

the flat head of a cyclone is not a circular flat plate and the vessel is not a regular cylindrical shell. It is difficult to get solutions by using elastic mechanic theory. By the aid of numerical simulation technology and ANSYS software, the stress classification method and the design-by-analysis rule (ASME, 2010b) are employed in detailed stress analysis. The dimensions are optimized and the reasonable stiffen plates will be thought about in the new design.

FINITE ELEMENT MODEL

Geometrical model: The geometrical model of a typical cyclone, which has nominal diameter 2000 mm and length approximately 10000 mm, is established as shown in Fig. 1.

Table 1 lists the dimensions of the main components used in the numerical simulations.

Element type: In this study, the cyclone is modeled by shell 63 elements. Shell 63 is an elastic shell element. It has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has 6 degrees of freedom at each node. Stress stiffening and large deflection capabilities are included.

Meshing: Model is meshed by using trilateral and quadrilateral elements in accordance with the geometrical size and structure characters.

Material property: The cyclone material is SA387-Gr.11 class 1. The material properties are based on ASME (2010c).

Restrictions and loads: Full restraints are applied on the upper end and free restraints are applied on the lower end. Internal pressure of 3.0 MPa is applied.

RESULTS AND DISCUSSION

Influence of having and without stiffened plates on the top cover: The Von Mises equivalent stress distributions of having and without stiffened plates are shown in Fig. 2 and 3. The calculation results show that very high stress exists at the internal and external edge for stress concentration. It is a good phenomenon that the stress reduces greatly after applying stiffened plate.

The external and internal edge stress distributions of upper cover with and without stiffened plates are shown in Fig. 4 and 5.

According to the numerical simulation, the stress value of the inlet top external edge is reduced by 18.5% after applying stiffened plates. While the stress value of the circular middle external edge has a 70% drop. The
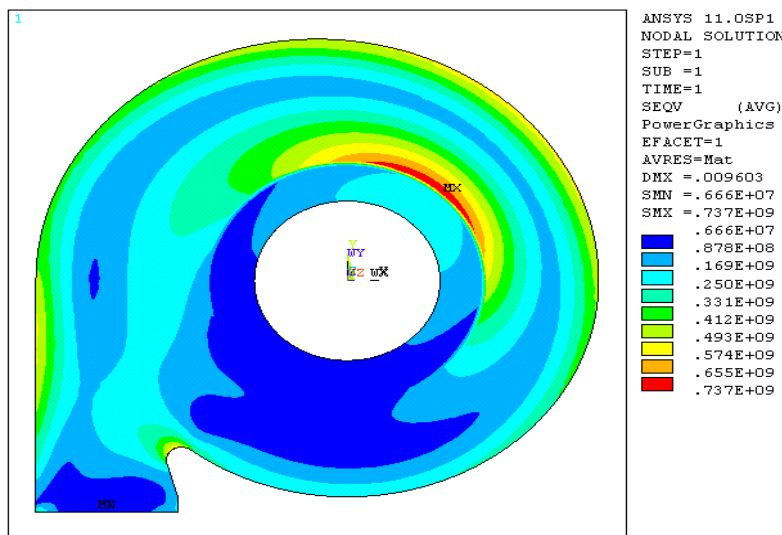

Fig. 2: Stress distribution of upper cover without stiffened plate
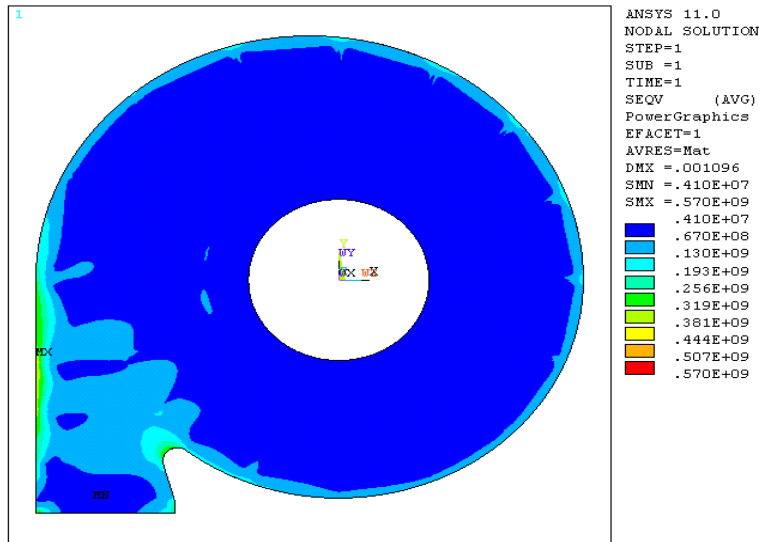
Fig. 3: Stress distribution of upper cover with stiffened plate
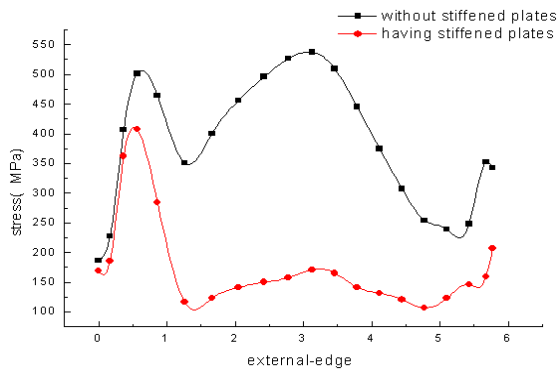

Fig. 4: Comparisons of stresses in external-edge of upper cover with and without stiffened plates
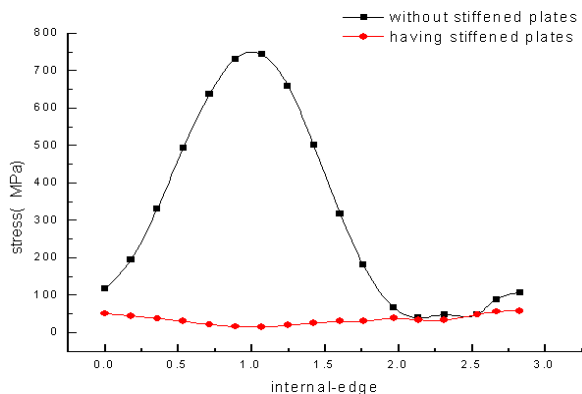

Fig. 5: Comparisons of stresses in internal-edge of upper cover with and without stiffened plates

stress at the beginning point of internal edge is 36.8% lower than that without stiffened plates. Meanwhile the stress of the circular middle internal edge has fallen enormously with a huge drop 81.9%. Obviously, the stresses are decreased and stress distributions are more
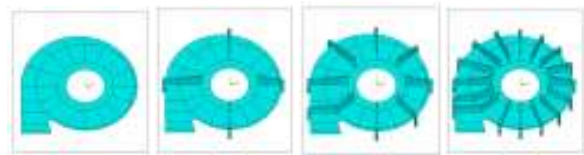
Fig. 6: Models of upper cover with different quantities of stiffened plates

uniform after applying stiffened plates. As a result, stiffened plates application is an effective option to reduce the stress and uniform the stress distribution.

Influence of numbers of stiffened plates on the top cover: Models with different quantities of stiffened plates are established as shown in Fig. 6. The stress distributions of upper cover with different quantities of stiffened plates are shown in Fig. 7 to 10. According to the numerical simulations, more stiffened plates are applied, more the edge stress value will be reduced, more uniformly the stress will distribute.

The external and internal edge stress distributions of upper cover with different quantities of stiffened plates are shown in Fig. 11 and 12.

According to the numerical simulation, the reduce range of external edge maximum stress changes from 55.6% to 68.2% with the increase of the plates. The stress difference of external edge changes from 351.15 MPa to 282.2 MPa with the increase of the plates.

Influence of having different thickness of stiffened plates on the top cover: Remain the plates quantity number 16 unchanged, models of cyclones with different thickness plates are established and the numerical calculations are completed.

The stress distributions of upper cover with different thickness of stiffened plates are shown in Fig. 13 to 16.
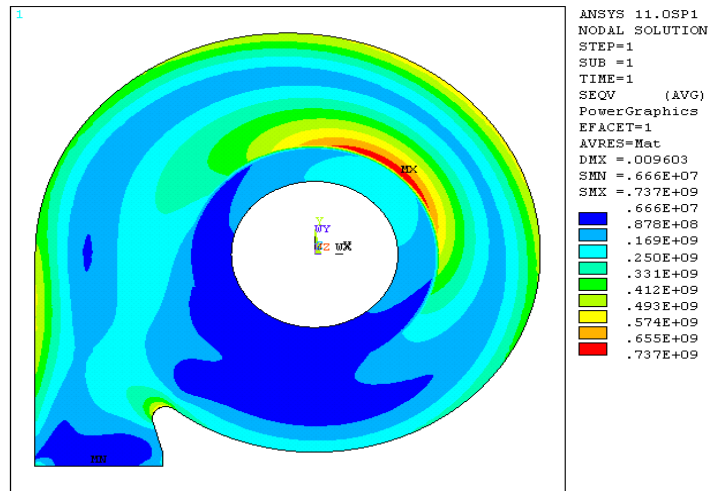
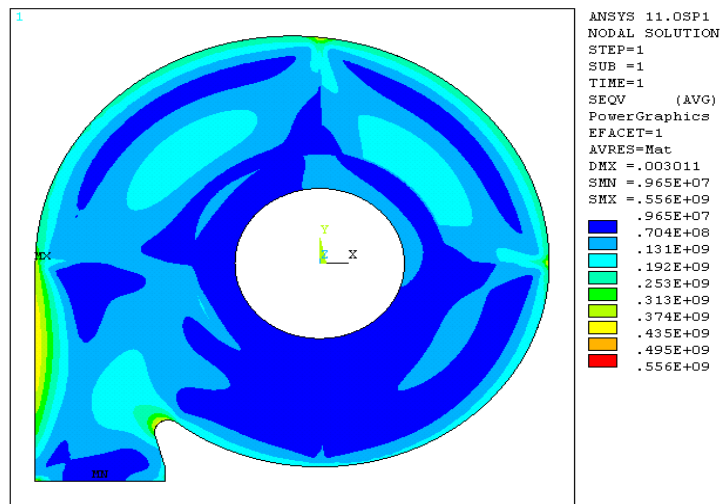Fig. 7: Stress distribution of upper cover with 0 stiffened plate

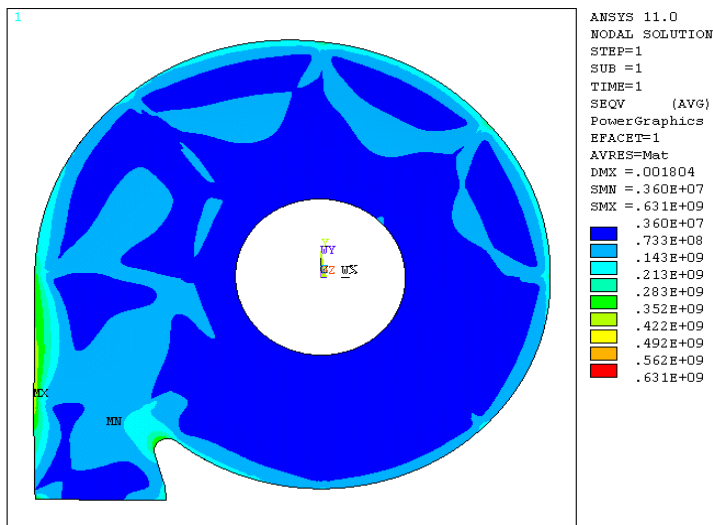Fig. 8: Stress distribution of upper cover with 4 stiffened plates

Fig. 9: Stress distribution of upper cover with 8 stiffened plates
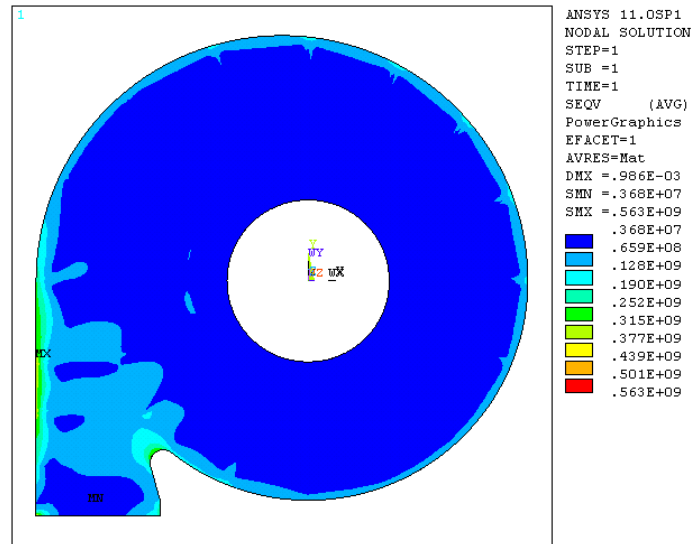
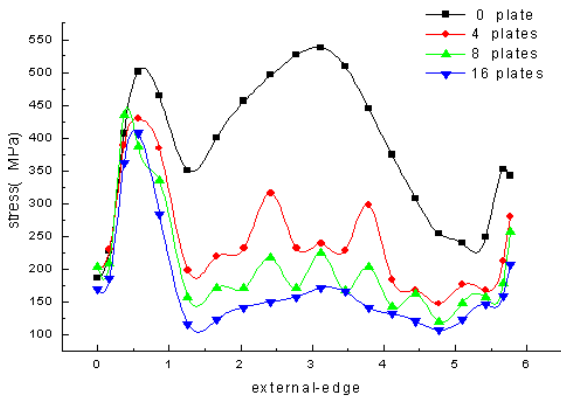Fig. 10: Stress distribution of upper cover with 16 stiffened plates

Fig. 11: Comparisons of stresses in external-edge of upper cover with different stiffened plates
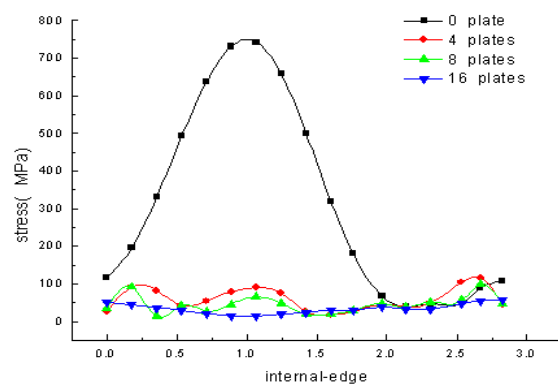

Fig. 12: Comparisons of stresses in internal-edge of upper cover with different stiffened plates
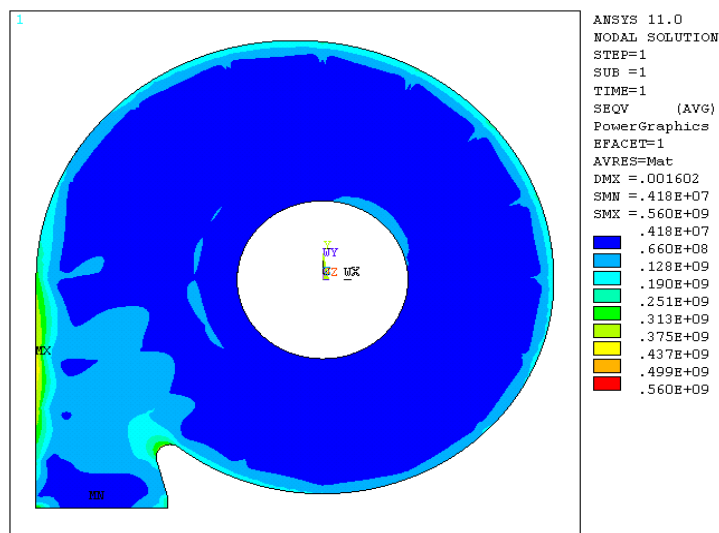

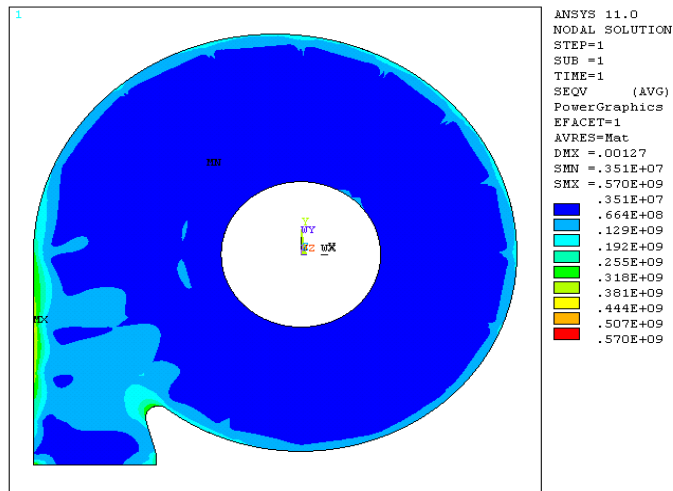Fig. 13: Stress distribution of upper cover with 18 mm stiffened plates

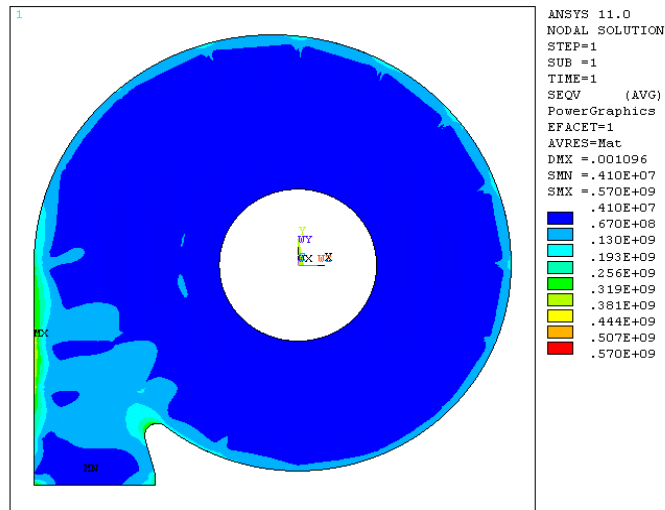Fig. 14: Stress distribution of upper cover with 30 mm stiffened plates

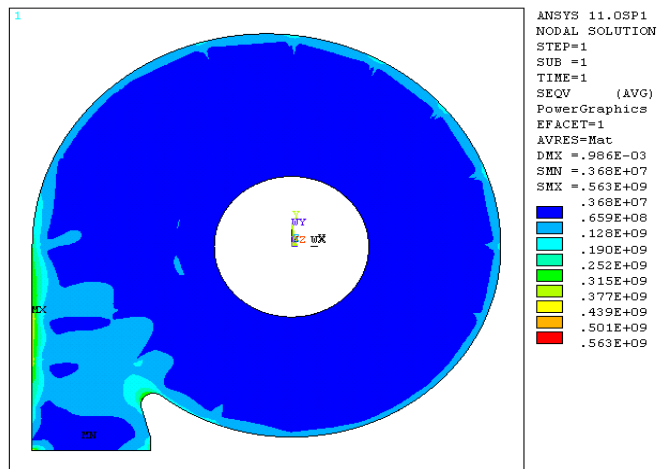Fig. 15: Stress distribution of upper cover with 42 mm stiffened plates

Fig. 16: Stress distribution of upper cover with 52 mm stiffened plat

In accordance with the simulation, thicker stiffened plates will decrease the stress value. The maximum stress changes from 374.7 MPa to 351.8 MPa while the stiffened plate thickness changes from 18 mm to 52 mm. The change range is not as enormous as that caused by plate quantity. It is unnecessary to design the plate thickness bigger than 42 mm in view of the manufacture cost.

CONCLUSION

- The traditional rectangular vortex inlet and flat head will be remained in the new-developed CAGG cyclones. In accordance with numerical simulation and analysis, application of stiffened plates is good for top head stress distribution. In the stiffened plates design, it is essential to optimize plate quantity and plate thickness.
- Adjusting the stiffened plate quantity is more effective and more economic than adjusting the stiffened plate thickness.
- The recommended quantity of stiffened plates is 8～16. The recommended thickness of stiffened plate is 30 mm.

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