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Thermal and Fatigue Analysis on Hot Box

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Abstract:
Delayed coke drums are integral part of delayed coking unit in petroleum refineries which converts petroleum residue into higher value petroleum coke by thermal cracking process. Coke drums experience thermal and pressure variations during process. Temperature fluctuations are severe and causes repetitive thermal stresses which leads to the fatigue failure at various locations and skirt to cone junction is being one of the critical. The purpose of the present study is to find an optimized skirt Hot-box junction geometry which will minimize thermal stresses and improve fatigue life. Axisymmetric model of coke drum is developed in ANSYS. Transient thermal analysis followed by structural analysis is carried out to obtain the stresses induced in coke drum during the cycle. Fatigue life is evaluated as per ASME BPVC Sec. VIII Div. 2 based on the stresses obtained. Key parameters like hotbox length, crotch radius, skirt thickness etc. are varied and their effect on the fatigue life is observed.

Index Terms: Coke drum, Hot Box, Fatigue life, Thermal Fatigue

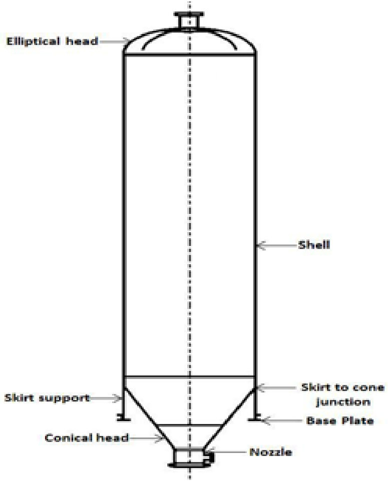
I. INTRODUCTION

DELAYED coke drums are insulated vertically oriented cylindrical pressure vessels used in the delayed coking process. Delayed coking process is used to convert heavy oil residue to produce gas product and petroleum coke. The dimensions of the coke drums are commonly 4.5 to 10 meter in diameter, and around 17 to45 meter in height. The pressure inside the coke drum goes around 500 kPa, and the maximum operating temperature ranges from 427 to 487°C. Fig 1 shows schematic of typical coke drum.

In recent years coke drums have received much attention as a result of relatively early failure in their operational life due to their inherently severe thermal operational cycling. Coke drums undergo severe thermal and pressure cycling on a daily basis. The skirt to shell and cone junction is a very critical portion of coke drum as it is highly susceptible to fatigue. The phenomenon of thermal fatigue plays very crucial role in failure of coke drums. These severe thermal-mechanical loadings cause lives of the coke drum to be shortened. The average operational life of the coke drum is above ten years. During their operational lives, coke drums also have to go through a series of repairs due to the damage that result in high cost associated with the production loss.

Therefore, it is important to improve the reliability and to extend the lives of the coke drums, which will save the maintenance cost, increase the production and especially ensure the safety of the operation.

Cathleen Shargayet. al[1] explained the issues in coke drum design and fabrication and suggested that design should be reviewed with a finite element stress analysis to ensure that it will meet the desired fatigue life. Some of the issues to be determined when developing a skirt design are Location of attachment weld (to cone or shell), Skirt thickness, Skirt center line location, Blended fillet weld design with a generous internal crotch radius, Use of keyhole slots, Use of a machined skirt-to-cone attachment forging etc.



M Sohel M Panwalaet. al[2] carried out fatigue analysis of coke drum hot box with skirt having slots at specific pitch all around circumference to induce flexibility. It was found that the most critical location for fatigue is the slot tip. The fatigue life at skirt to cone junction is increasing with increase in crotch radius. But, this increase in crotch radius adversely effects on slot tip where the life is drastically reducing. It was concluded that inner crotch radius should be studied and optimized considering the life at both skirt to cone junction and slot tip. This will ensure the structural integrity of skirt during the process operation.

Nirmal Pravin Chandra et. al[3]carried out fatigue analysis of coke drum hot box with axisymmetric model. It was observed that increasing the length of the hot box, the value of alternating equivalent stress decreases and hence the fatigue life of the skirt support increases. This shows that hot box length is one of the important factors which affect the life of coke drum. The purpose of present study is to find the parameters affecting the fatigue life and improve the fatigue life by altering the identified parameters.

II. FEA OF COKE DRUM HOT BOX

Axisymmetric model of coke drum hot box is prepared in ANSYS® APDL, the skirt to shell junction is modeled along with insulation on outer side, fireproofing at bottom inside part of skirt, cladding on the inner side of coke drum as shown in fig.2. Material of construction for Shell, cone and skirt is SA 387 Gr.11 Cl. 2, SA 516 for Baseplate, and SA 240 for Cladding. Material properties for analysis are taken from ASME BPVC Sec. II part D.

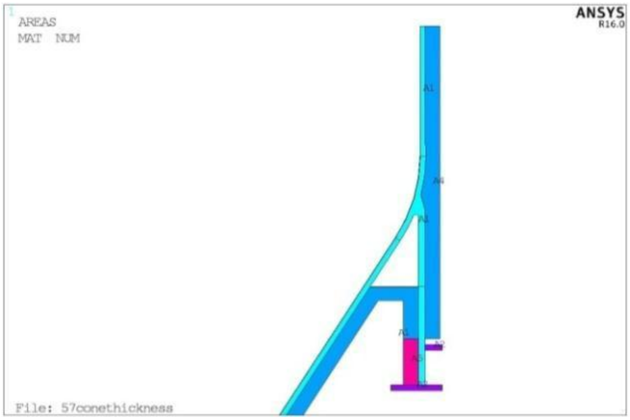


Fig.2 Axisymmetric model of coke drum.

Fig 3 shows the discretized model of coke drum. Element type PLANE 77 is used for the thermal analysis which is the changed into corresponding structural element PLANE 183 for structural analysis.

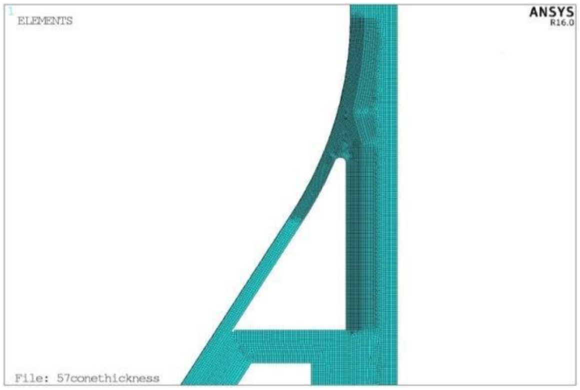


Fig.3 Discretized model of coke drum

2.1 Thermal Loading and Boundary Condition Inside surface temperature is varying according to process, typical temperature cycle is shown in fig.4. Two cycles has been considered in analysis in order to obtain steady results. Outside convection coefficient is taken as 3.58 W/m^2°C and ambient temperature as 35°C. Radiation is provided on inside surface of hot box with emissivity 0.8 on all the surfaces in closed enclosure with Stefan boltzman constant taken as 5.67e-8 W/m$^{2°}$K^4.

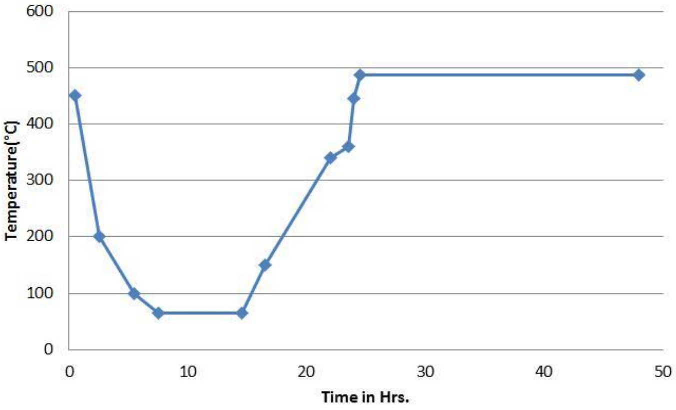


Fig.4 Typical thermal cycle of coke drum.

2.2 Structural Loading and Boundary Condition Internal pressure according to pressure cycle is applied at each load steps as shown in fig.5, pressure thrust is applied on shell and nozzle, dead weight of coke drum is also applied on top edge of model. Base ring of coke drum and node at bolt location is fixed in both x and y directions.

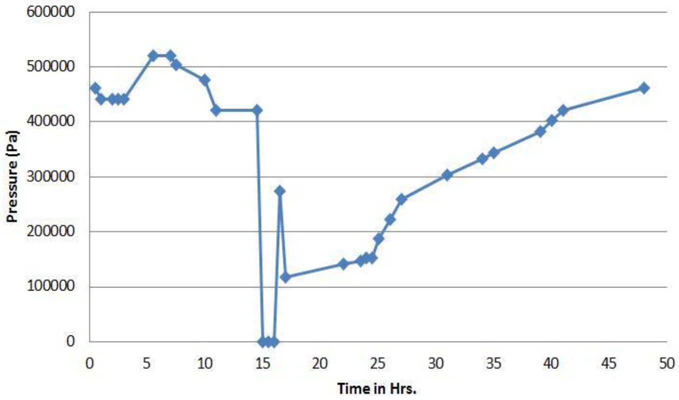


Fig.5 Typical pressure cycle of coke drum.

III. FATIGUE ANALYSIS

The fatigue evaluation is performed as per Para 5.5.3 (Fatigue assessment – Elastic stress analysis and equivalent stress) of ASME BPVC sec. VIII div. 2. The values of the stress tensors for thermal plus mechanical loading and local thermal stresses are obtained from the stress analysis and alternating equivalent stress is obtained by using the equation given below. Fatigue life is evaluated based on the alternating equivalent stresses obtained.

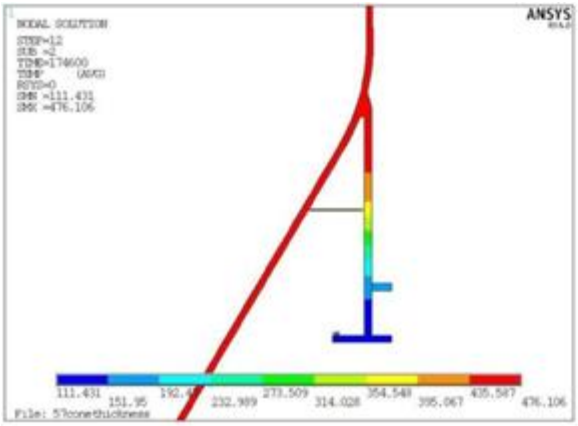


Fig.6 Temperature plot at steam out (0.5 hrs).

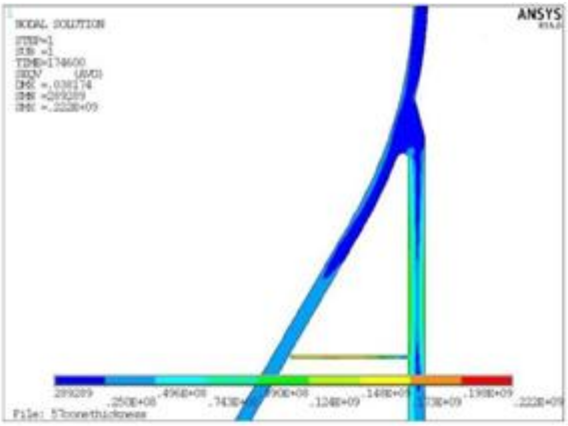


Fig.10 Stress plot at steam out (0.5 hrs).

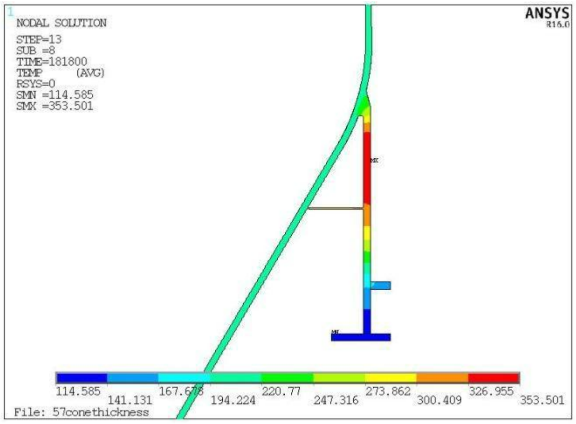


Fig.7 Temperature plot at water quenching (2.5 hrs).

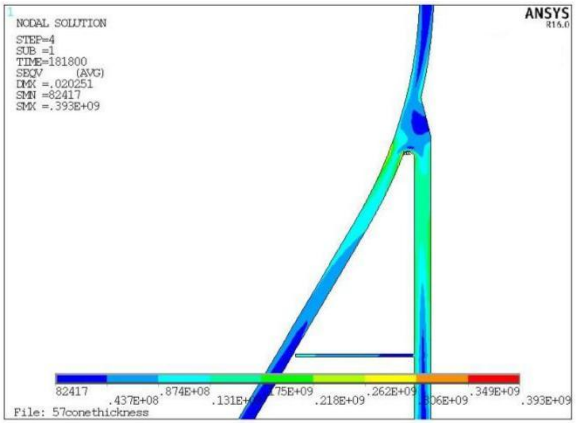


Fig.11 Stress plot at water quenching (2.5 hrs).

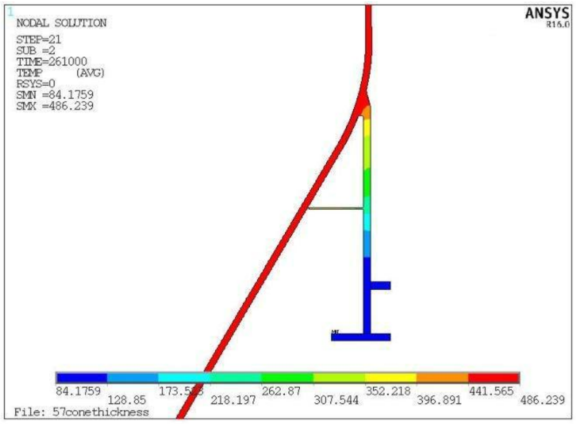


Fig.8 Temperature plot at coking (24.5 hrs).

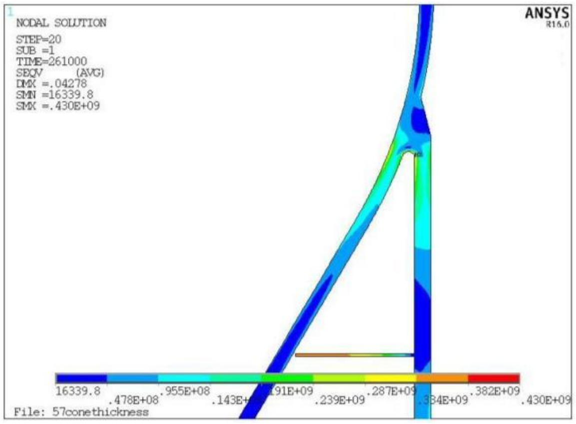


Fig.12 Stress plot at coking (24.5 hrs)

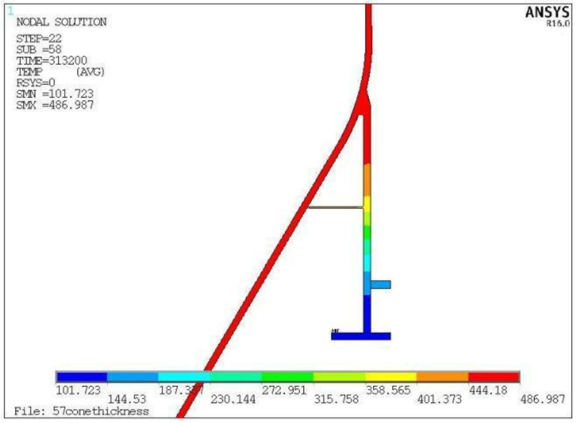


Fig.9 Temperature plot at coke cutting (39 hrs).

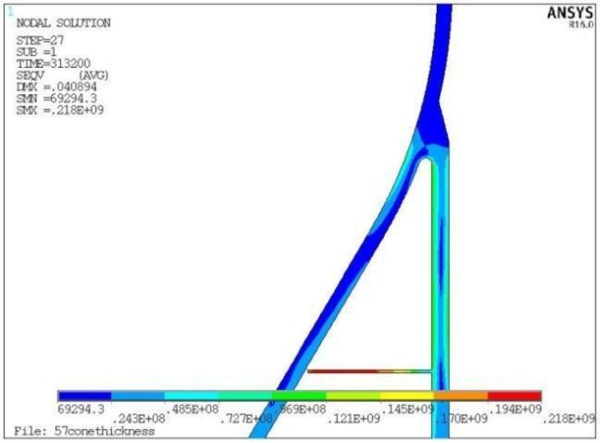


Fig.13 Stress plot at coke cutting (39 hrs).

RESULTS AND DISCUSSIONS

Transient thermal analysis is performed to obtain the temperature distribution and it is followed by structural stress analysis to obtain stresses due to temperature and pressure loading. The stresses are obtained at each load steps. The location of maximum stress is identified and the time in the cycle at which it is having peak values is identified by tracking node at that location as shown in fig.14.In this case node inside skirt near skirt to cone junction has maximum equivalent stress and itis considered for tracking, according to which water quenching process at 2.5 hrs and coking process at 24.5 hrs shows the peak values and hence stress components at these 2 points are considered to obtain the alternating equivalent stress as per ASME code.

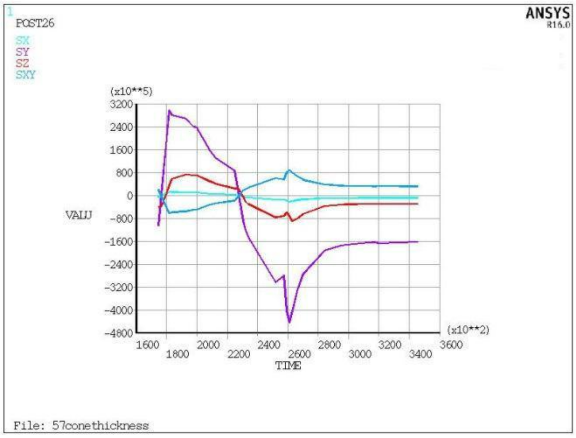


Fig.14 Variation of stress components at maximum location.

Fig.6-9 shows the temperature distribution in coke drum for various time steps. Fig 10-13 shows the equivalent stresses generated in coke drum at respective time steps. The stress plot shows that maximum stress location in water quenching process is at node near the conical head and maximum stress location in coking process is at node near skirt.

4.1 Variation in crotch radius

Crotch radius of the skirt to cone junction is varied from 20 mm to 35 mm. As the radius increases the equivalent stress produced at junction decreases as shown in fig.15.

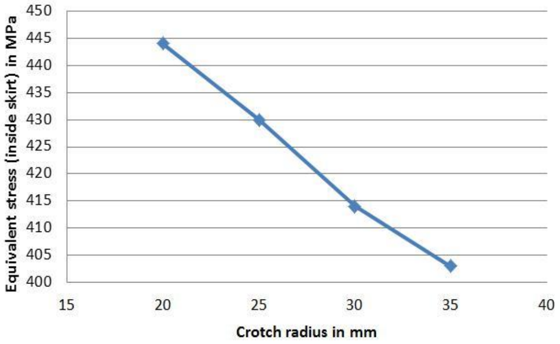


Fig.15 Equivalent Stress vs. Crotch radius

Alternating equivalent stress is evaluated from stresses obtained in stress analysis as per ASME code. Fig. 16 shows the alternating equivalent stress for different crotch radius. It shows that alternating equivalent stress decreases as increase in radius and comes to minimum for the crotch radius 30mm and again starts increasing as the radius increases.

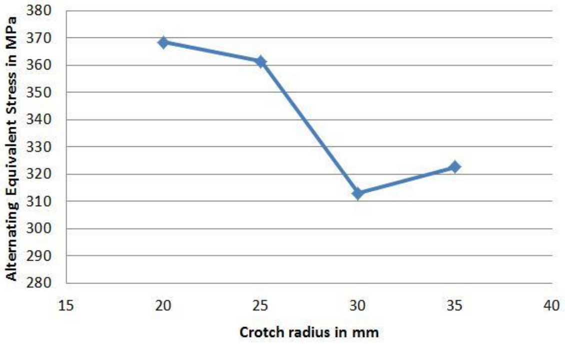


Fig.16 Alternating Equivalent Stress vs. Crotch radius.

Fig. 17 shows Fatigue life evaluated at different crotch radius. No. of cycles at crotch radius 30mm is highest as the alternating stress calculated is minimum.

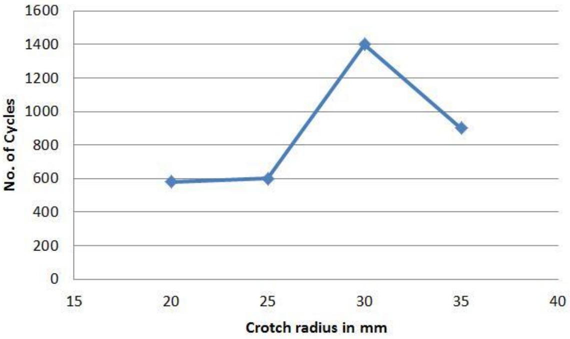


Fig.17 No. of cycles vs. Crotch radius

4.2 Variation in hot box length

Hot box length of the coke drum is varied from 850 mm to 1000 mm. As the hot box length increases the equivalent stress produced at junction decreases slightly as shown in fig. 18.

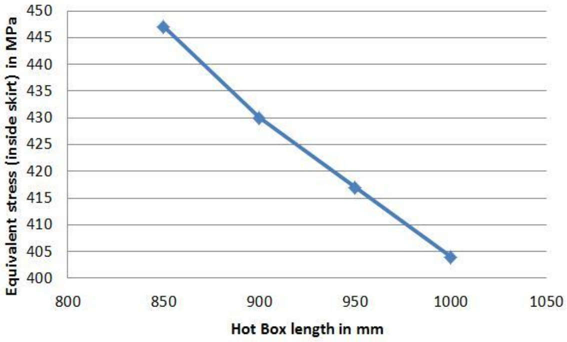


Fig.18 Equivalent stress vs. Hotbox length

Fig. 19 shows the alternating equivalent stress for different hot box length. It shows that alternating equivalent stress decreases with increase in hot box length but the reduction is not very significant.

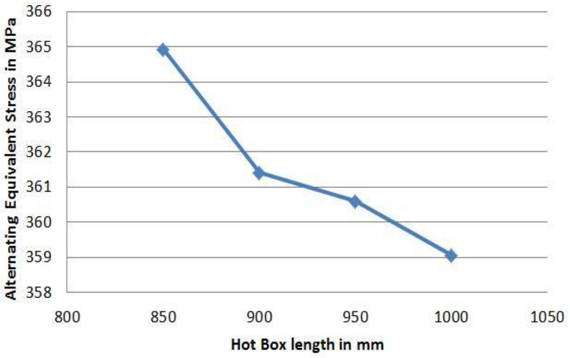


Fig.19 Alternating Equivalent Stress vs. Crotch radius.

Fig. 20 shows fatigue life evaluated at different hot box length. It shows that after certain hot box length the fatigue life does not vary much with increase in length as the decrement in alternating equivalent stress is very less.

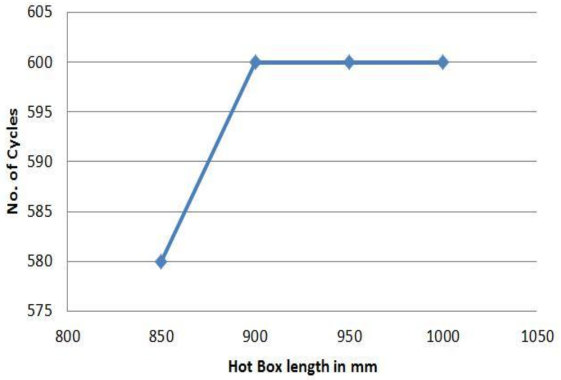


Fig.20 No. of Cycles vs. Hot Box length.

4.3 Variation in other key parameters

Parameters such as skirt thickness, skirt centerline location are also varied and their effect on fatigue life is observed. Changing these parameters does not show any specific trend in variation of fatigue life.It is also observed that cone thickness has significant effect on fatigue life however cone thickness is obtained during designing of coke drum based on requirements, hence it should be checked with finite element analysis in order to obtain optimum skirt junction geometry to maximize fatigue life.

CONCLUSIONS

1. Maximum stress locations are observed at the skirt to cone junction.

2. Crotch radius affects the fatigue life significantly, hence FEA of coke drum should be carried out to decide the ideal crotch radius.

3. Increase in hotbox length reduces the stresses induced slightly but does not improve fatigue life by substantial margin.

4. Varying skirt thickness, cone thickness etc. affects the fatigue life and these parameters shouldalso be considered while obtaining the optimum skirt to cone junction geometry.

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