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Research Article

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Finite element analysis of embedded pipes inside pressure vessel

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ABSTRACT

Chemical Processes are widely carried out by means of heat. Heat is used to maintain viscosity of fluid that is stored. Naphtha is heavy oil which is stored in process reactionary vessel. If the temperature drops the fluid becomes viscous and can cause considerable damage to the system. To overcome this problem the embedded pipes are introduced in the system which maintain the temperature of the system. Present research work proposes the two designs of embedded heat pipes into the system. The pressure vessel is designed using ASME standards and modeling is done on the ANSYS design modeler. FEA Simulation is carried out using different cases to check the total deformation and stress and select the optimized design. The result shows that the U-shaped embedded pipe gives less deformation and stress than the C-shaped embedded pipe.

Keywords: Process reactionary vessel; Embedded heat pipes; ASME.

INTRODUCTION

Naphtha is obtained by the distillation process in petroleum refinery of coal tar. Petroleum naphtha is petroleum distillate which contains the aliphatic hydrocarbons and boiling point is higher than the gasoline and lower than kerosene. The initial boiling point of naphtha is about 35ºC and final boiling point of about 200ºC. Chemical basis, Naphtha contains different amount of constituents (paraffins, naphthenes, aromatics, and olefins) in different proportions. [1-2]

Heat pipe is the passive component of a self- sufficient vacuum closed system as it includes the capillarity structure and the filling of working fluid usually to soak through the entire capillarity structure. When the pipe works, the evaporation section of the heat absorption occurs in the capillarity structure. [3]

The fundamental construction of the traditional heat pipe is shown in Figure 1.

The heat pipe uses the working fluid with much latent heat and transfers the massive heat from the heat source under minimum temperature difference.[4]

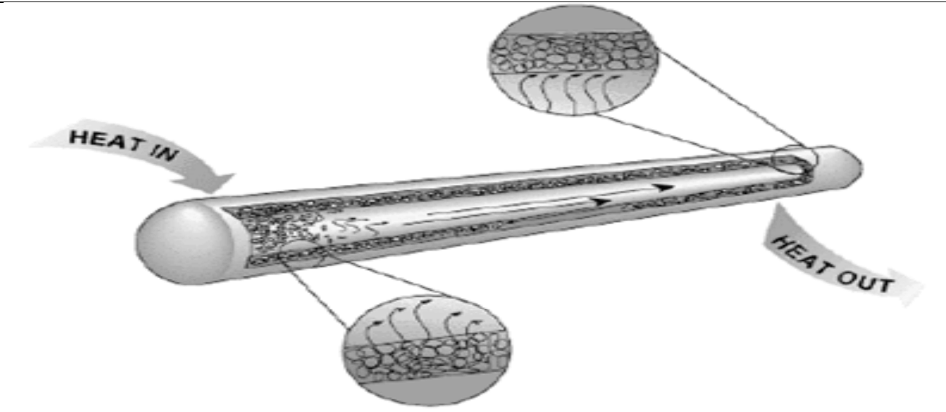


Fig 1.The basic structure of conventional heat pipe [3]

Although the heat pipe has good thermal performance for lowering the temperature of the heat source, its operating limitation is the key design issue called the critical heat flux or the heat capacity quantity.

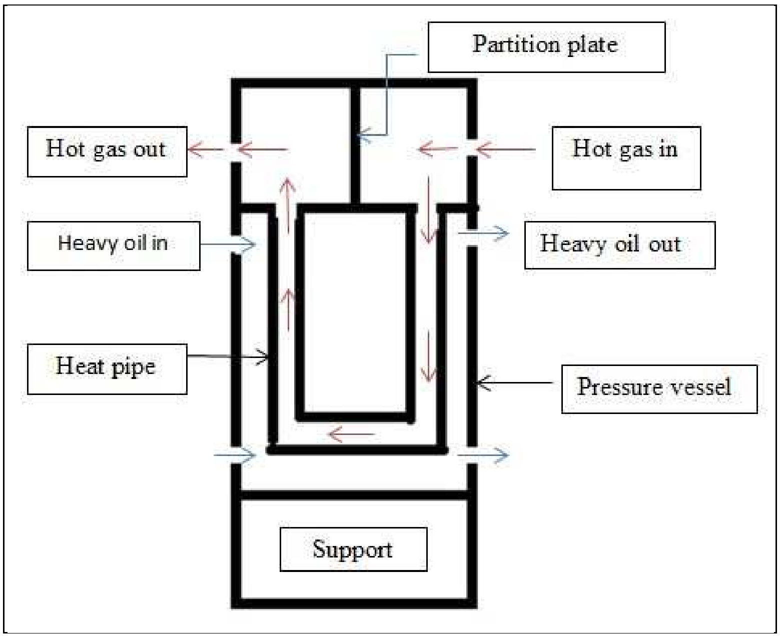


Fig 2.Basic layout of Process reactionary vessel with embedded pipes

Figure 2 illustrates the working of process reactionary vessel with embedded heat pipe. Heavy oil is stored in the vessel called as process volume (Vs). This oil is stored for further process at a certain temperature to avoid the phase change. For that embedded heat pipe are inserted in the vessel and hot gas is allowed to pass through it by maintaining pressure difference. Due to pressure and temperature difference the uneven thermal stresses are developed in the system which will compromise the safety of the structure. So to avoid this optimum embedded pipe is needed to stabilize the design.

DESIGN OF PRESSURE VESSEL AS PER ASME CODES

MATERIAL PROPERTIES [7]

Carbon steel ASME SA516 Grade 70

Maximum allowable stress (S) = 20000 psi = 138 MPa

Modulus of elasticity E = 200 GPa

Poisson’s ratio $\mu = 0.29$

SHELL THICKNESS
S= 138MPa
E_l=0.7 longitudinal seam efficiency (circumferential stress)
E_e=0.85circ seam efficiency (longitudinal stress)
P_i = 0.3859 MPa
R = 2500mm
Corrosion Allowance (CA) = 6

From ASME SECTION VIII, div –I, UG27
Thickness of shell due to internal pressure [6-7]
= $(P_i*R)/(S*E-0.6*P)$
= (0.3859*2500)/(138*0.7-0.6*0.3859)
t_a=10.01mm
$t_b=(P_i*R)/(2*(S*E)+0.4*P)$
=(0.3859*2500) / (2*(138*0.85)+0.4*0.3859)
t_b= 4.109mm
T_{req}= Maximum (t_a , t_b) + CA
T_{req}= 10.01 + 6
Treq = 16.01mm nt =18mm

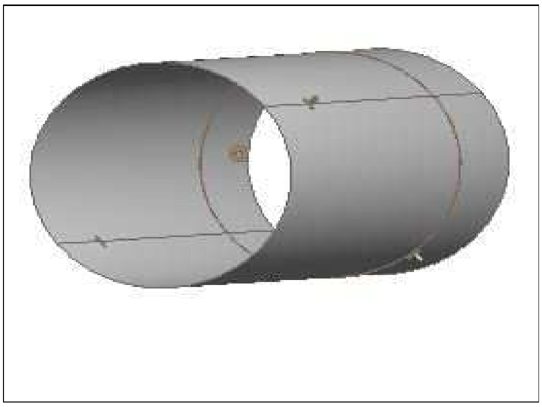


Fig 3.Shell Model

Flat Head (UG- 32)
Thickness of Flat Head due to internal pressure [5]
t_h= $0.7*d_i (\sqrt{P_i}/SE)$+CA
=0.7*5000(($\sqrt{}$0.3859/138.57)+6
t_h= 190.70mm

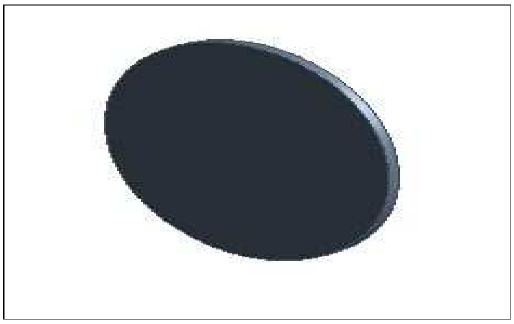


Fig 4. Flat head Model

Table 1 Shell Parameters

Internal pressure (P)	0.05MPa
Design temperature	$60^{O}C$
Shell height	26000mm
Shell Material	SA516 Grade 70
Shell Allowable Stress (at design Temperature)	138MPa
Shell Allowable Stress (at Ambient temperature)	138MPa
Flat Head diameter	5000mm
Flat Head thickness	190.70
Main Nozzle to Nozzle Centre Distance(Inlet/Outlet)	11500mm

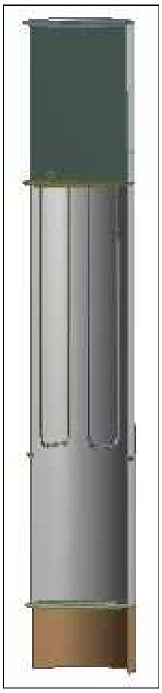
Table 2 Embedded C-shape Pipe Parameter

Pipe diameter	200mm
Pipe thickness	50mm
Total length	12000mm

Table 3 Embedded U-shape pipes Parameter

Pipe diameter	200mm
Pipe thickness	50mm
Total length	12000mm
U-shape radius	1250mm

CAD Model



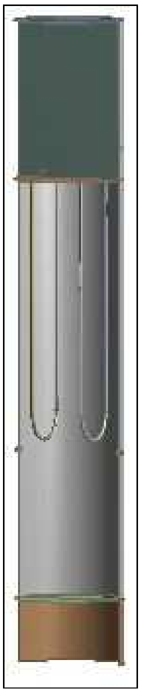


Fig 5. C section Model **Fig 6. U section model**

PREPROCESSING

Shell Mesh

Element Description

Element **shell 93** has been used in order to mesh the structure of column. It is second order shell element which supports all six degree of freedom (i.e. Translation along x, y, z axes and rotation about x, y, z axes respectively).it has both bending and membrane capabilities. Both in plane and normal loads are permitted. It also includes stress stiffening large deflection capabilities.

Thickness of shell applied as real constant value. Half of the thickness is applied above mid plane and half of the thickness is applied below the mid plane. All results are available at the mid plane. [8-9]

Number of nodes =151946

Mesh Model

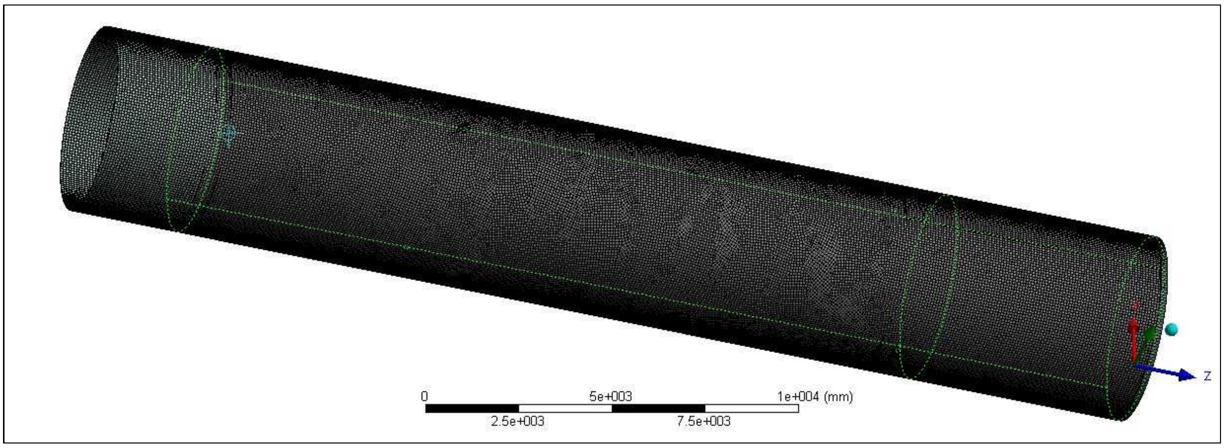


Fig 7. Shell Mesh Model

Embedded Pipe Mesh

Element Description

Element SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.[8-9]

C- Tube Mesh

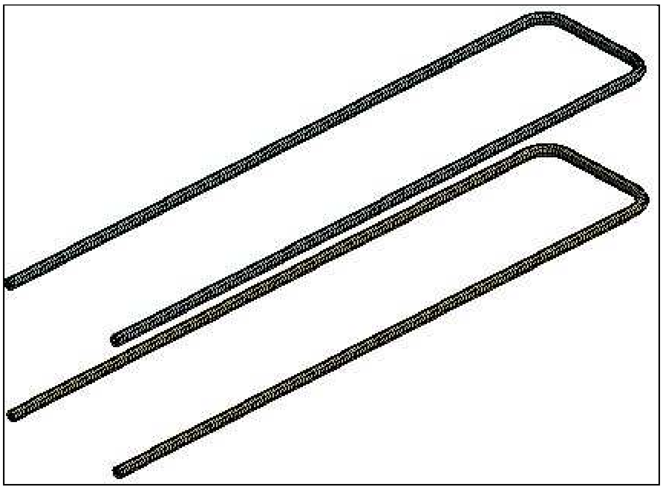


Fig 8. C- Tube mesh

U- Tube mesh

Fig 9. U- Tube mesh

Number of nodes for C- Pipe = 152000
Number of nodes for U- Pipe = 152170

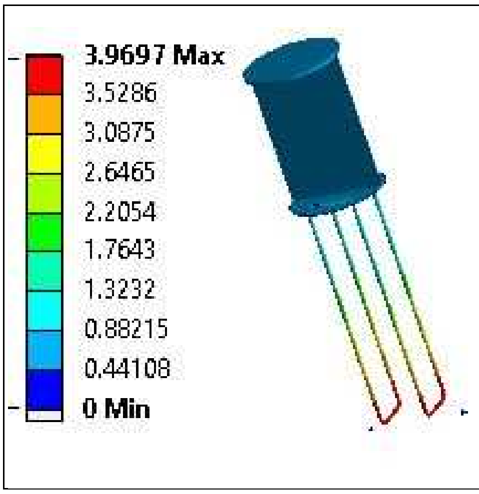
Assumptions

1. The small size nozzle, inlet-outlet pipe and other mouting and accessories are not consider for the purpose of FEA analysis.(Because the wieght of these devices are very small compared with weight of the entire column)
2. The vertical storage column is considered as thin pressure vessle because of (diameter to thickness ratio is greater than 20)
3. The cad model is meshed with second order shell element (SHELL 93)
4. The Skirt support is fix to individual cocrete column.
5. For static analysis the welding is not require to simulate because the weld material and parent material are assumed to be same(and the stress is independent from the material).therefor entire structure is consider as a continous structure.

RESULTS AND DISCUSSION

CASE 1: The two models which are taken should be structurally safe. In that case models are simulated for self-weight criteria. The structure is fixed at the skirt support and standard earth's gravity is applied to check the total deformation in the structure.

TOTAL DEFORMATION



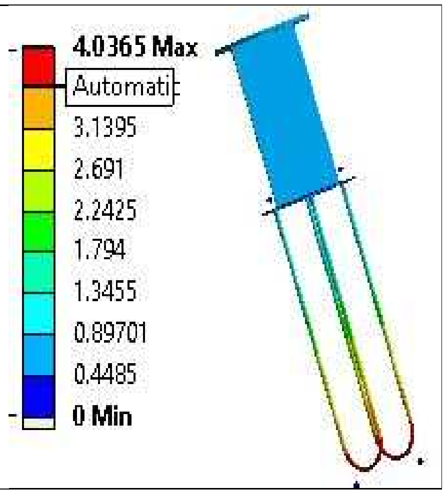
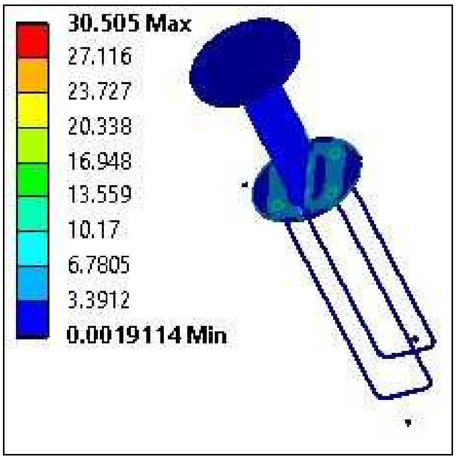


Fig10. C- Pipe total deformation **Fig11. U-pipe total deformation**

For Static loading the allowable deformation is given by L/300
Where L is the total height of the vessel =26000mm
= 26000/300
= 86.66 mm

As the total deformation is less than the allowable deformation both model are safe for the self weight criteria.

VON – MISES STRESS



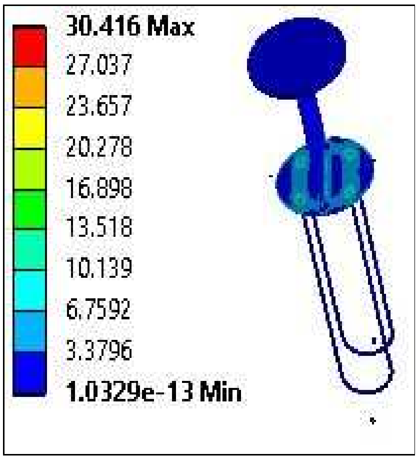


Fig 12. (von – mises)stressC-shape **Fig 13. (von – mises)stressU-shape**

The allowable stress given is 138MPa according to ASME codes. As both the models are within the limits but U-shape Pipe gives less stress compared to C- shape Pipe.

CASE 2: Steady state temperature of 60^{o}C is applied to the embedded pipes and internal pressure of 0.05MPa to the innner surface of the pipe.

As the vessel will be filled with Naphtha it will exibit theBuoyancy force of 14690 N to the structure. So the total deformation and stress will be checked for both the models.

TOTAL DEFORMATION

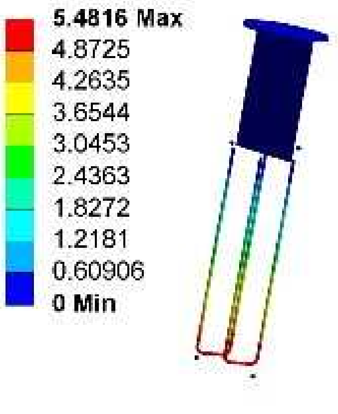


Fig 14. C- Pipe total deformation

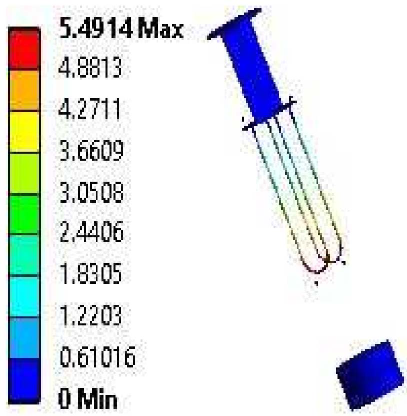


Fig 15. U-pipe total deformation

VON – MISES STRESS

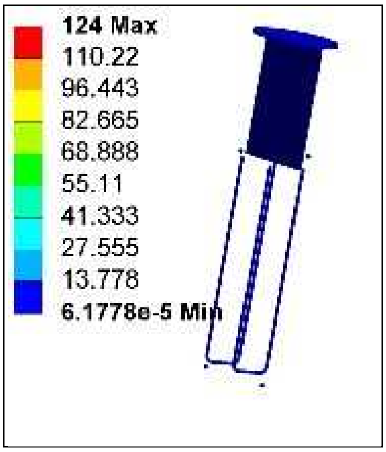


Fig 16. (von – mises) stress C-shape

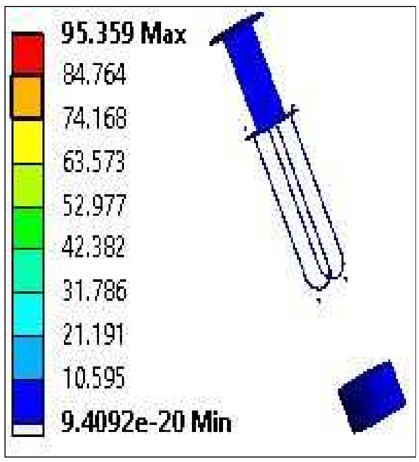


Fig 17. (von – mises) stress U-shape

In case 2 comparing figure 14. And figure 15. the total deformation has negligible effect but it is clear from figure16. and figure 17.the stresses developed in C-shape is more than the U- shape embedded pipe.

Sr. no.	Analysis	C- Shape Embedded Pipe		U-Shape Embedded Pipe	
		Deformation	Stress	Deformation	Stress
1	Self-weight	3.9697mm	30.505MPa	4.0365mm	30.416MPa
2	60^{o}C Temperature to Pipe, Buoyancy	5.4816mm	124MPa	5.4914mm	95.359MPa

CONCLUSION

In this paper , numerical simulation was conducted by using FEM software on C- shape embedded pipe and U-shape embedded pipe. After comparing the simulated results of total deformation and (von- mises) stress pressure vessel with U-shape embedded pipe is structuraly safe than the pressure vessel with C-shape embedded pipe. Also the heat distribution is much efficeint.

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