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Study of limit load and stress distribution in the design of two-phase separator for geothermal power plant

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ABSTRACT

A two-phase separator is a very important component of a geothermal power plant system. The main function of the Separator is to remove liquid from the geothermal fluid mixture and ensure that the steam entering the turbine to turn the turbine is dry and clean. This paper presents the results of a finite element study to determine the limit load (internal pressure) and to assess the stress distribution of vertical cyclone separator tank designed with three design methods commonly used in geothermal power plant systems: Bangma, Lazalde-Crabtree, and Spiral Inlet methods. These design methods mainly differ in the opening structure of the main shell for the two-phase inlet to obtain the effect of centrifugal force for the separation of water and steam in the Separator. Opening in the shell causes a reduction in the ability of the shell to withstand internal pressure load. The Separator was designed for a capacity of 375.27 tons per hour. It is a typical two-phase separator used in PGE units 3 and 4 Ulu Belu, Lampung, Indonesia. Design pressure (p_D) and temperature were 970 kPa and 200^{0}C, respectively. With these design conditions, the diameter of the inlet pipe to the main shell of the Separator (D_t) is 881 mm. The limit load was obtained via the finite element method using ANSYS nonlinear capability with the Newton-Raphson option turned on. It was found that the limit load of the Separator designed using the Bangma, Lazalde-Crabtree, and Spiral Inlet is 1.726 p_D, 1.28 p_D, and 1.087 p_D, respectively. For the Bangma method, the maximum stress along the axial direction measured from the inlet is located at $1.18\sqrt{rt}$ and decays at $5.89\sqrt{rt}$. It was concluded that the Bangma method results in higher stress in the shell but has a higher limit load compared to the other two methods.

Keywords: Bangma, Lazalde-Crabtree, Spiral Inlet, Limit Load, Stress Distribution, Maximum Stress

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INTRODUCTION

A two-phase Separator is a very important component in a geothermal power plant system. The main function of the Separator is to remove liquid from a geothermal fluid mixture by separating the water carrying salt and other solid objects that can cause scaling and corrosion of equipment, especially turbines. The Separator is useful for ensuring that steam enters the turbine to turn the turbine is really dry and clean. There are two types of separators commonly used in geothermal power plants, i.e., horizontal separators and vertical separators. The Separator is generally cylindrical.

Horizontal Separator uses gravity to separate water and steam. Water with a higher density will fall on the bottom Separator and will be separated from the steam stream. Horizontal separators are usually used for fluids with a high gas-liquid ratio, whereas Separator vertical is used for fluids with a low gas-liquid ratio [1]. In general, for the same flow rate, a horizontal separator requires a larger diameter than a vertical separator [2]. On the other hand, horizontal separators are simpler to construct and operate than vertical separators.

A separator with a vertical design is used to separate steam from brine in geothermal fields with a low gas-liquid ratio (liquid-dominated). Vertical separators utilize centrifugal force to separate steam and water. Steam with a lower density than water tends to flow in the middle area of the vessel, while liquid flows on the wall of the Separator, causing the liquid to lose its momentum and fall on the bottom Separator due to gravity.

Most geothermal fields worldwide are liquid-dominated [3]. Steam and liquid separation takes place in a vertical separator due to centrifugal force (cyclone separator). The quality of purity (percent of vapor) is separated depending on the input flow rate of a two-phase mixture of steam and water that goes into the Separator and also on the separator construction.

Bangma [4] designed a vertical separator with steam from the separation out on the bottom Separator. Bangma's design is known as the Bottom Outlet Cyclone (BOC) Separator. After analyzing theoretically the influence of various variables on the quality of the steam from the separation, Bangma concluded that the quality of vapor separation depends on the ratio of the two-phase mixture of steam and water, as well as the velocity of two-phase mixed input enters the Separator. From his analysis after carrying out a series of tests to produce the highest quality separation steam, Bangma proposed the dimensions of the Separator in terms of two-phase input diameter.

Lazalde-Crabtree [5] conducted an empirical study and recommended some guidelines for designing a two-phase vertical separator for a geothermal power plant. From his study, Lazalde-Crabtree recommended the parameters geometry of the Separator.

Another design method of a two-phase steam-water Separator is the spiral inlet design [6] The input pipe to the Separator is square in shape. Table 1 summarizes the comparison of parameter design according to the Bangma, Lazalde-Crabtree, and Spiral Inlet. Figure 1 is the parameter geometry of the Separator. Note that all parameter geometry are written in terms of inlet diameter, D_t.

The three design methods [4, 5, 6] are commonly used to determine the dimensions and geometry of vertical separators. The recommended parameter was based on separation efficiency. It does not consider the stress behavior of the main shell. These three methods are broadly different in two-phase inlet construction on the Separator which produces different stress behavior on the cylinder shell. This paper presents the results of a finite element study to determine limit load (internal pressure) and evaluate the stress behavior at the main shell of a two-phase Separator designed using Bangma, Lazalde-Crabtree, and Spiral inlet.

Tabel 1. Parameter geometri of separator [7]

Parameter	**Bangma Design**	**Lazalde-Crabtree Design**	**Spiral-inlet design**
D	$3\ D_t$	$3.3\ D_t$	$2.95\ D_t$
D_e	$0.8\ D_t$	$1\ D_t$	$1\ D_t$
D_b	$1\ D_t$	$1\ D_t$	$0.7\ D_t$
α	$3.25\ D_t$	$0.15\ D_t$	$0.28\ D_t$
β	$3\ D_t$	$3.5\ D_t$	$3.2\ D_t$
Z	$3\ D_t$	$5.5\ D_t$	$5.8\ D_t$
L_T	$7\ D_t$	$6.475\ D_t$	$6.8\ D_t$
L_B	$4.5\ D_t$	$4.975\ D_t$	$4.9\ D_t$

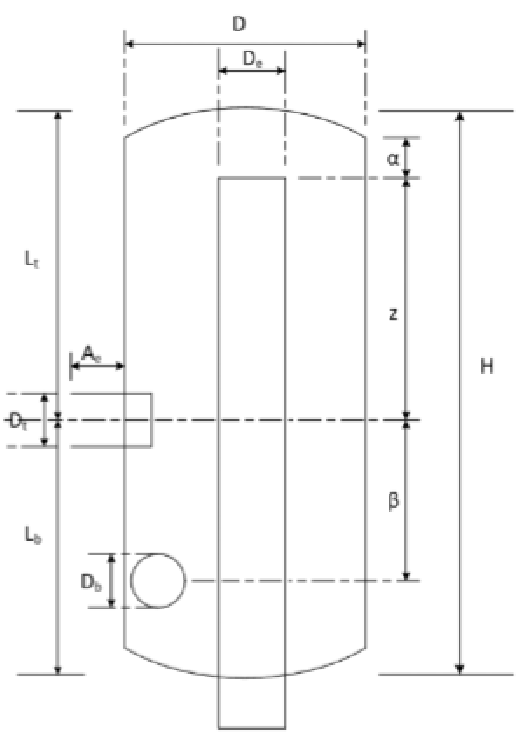

Figure 1. Parameter geometri of Separator [7]

FINITE ELEMENT METHOD

Finite Element Analysis using ANSYS is implemented to determine limit load and to assess the stress distribution for two-phase separators designed according to Bangma method, Lazalde-Crabtree method, and spiral inlet design. In general, finite element analysis using ANSYS consists of three phases: pre-processing, solution, and post-processing.

Geometry Modeling

The dimension of the steam-water Separator for the geothermal power plant is dictated by separation pressure and two-phase flow rate entering the Separator. DiPippo [6] recommended the range of steam velocity at the 2-phase inlet pipe between 20 and 40 m/s.

The diameter of the inlet pipe is a single parameter to determine other parameters of separator geometry as shown in Tabel.1. Diameter of inlet pipe D_t is calculated from cross-section area A of the inlet pipe:

$$D_t = \sqrt{\frac{4A}{\pi}} \qquad (1)$$

The cross-section area of the inlet pipe is determined from the equation of volume flow rate:

$$\dot{Q} = Av \qquad (2)$$

The design capacity of the Separator is 375.27 ton/h. It is the capacity of Separator of PGE Ulu Belu Unit 3, and 4, Lampung, Indonesia (personnel communication). Design temperature and pressure is 0.97 MPa and 200^{0}C respectively. From any Engineering Thermodynamic textbook, the density of steam for these design temperature and pressure conditions is 0.84 kg/m^3. From this, the steam volume flow rate is:

$$\dot{Q} = \frac{375.270\ \text{kg/h}}{6.840\ \text{kg/m}^3} = 15.24\ \text{m}^3/\text{s}$$

For an inlet velocity of 25 m/s [6], the cross-section area of the inlet pipe can be calculated from equation (2):

$$A = \frac{15.24\ \text{m}^3/s}{25\ \text{m/s}} = 0.6096\ \text{m}^2$$

Furthermore, the diameter of inlet pipe is calculated from Equation (1):

$$D_t = \sqrt{\frac{4\left(0.6096\ \text{m}^2\right)}{\pi}} = 0.881\ \text{m} = 881\ \text{mm}$$

Using this single parameter, other parameters corresponding to the geometry parameter in Figure 1 can be determined according to Tabel 1. The dimensions of the Separator are given in Table 2.

Table 2. The geometry parameter of the Separator

Parameter	Bangma Design (mm)	Lazalde-Crabtree (mm)	Spiral inlet (mm)
D	263.01	2907.31	2598.96
D_c	704.80	881.00	881.00
D_b	881.00	881.00	616.7
α	2863.26	132.15	246.68
β	2643.01	3083.51	2819.21
Z	2643.01	4845.51	5109.82
L_T	6167.03	5704.50	5990.82
L_B	3964.52	4382.99	4316.92

Figures 2, 3, and 4 show the Bangma, Lazalde-Crabtree, and Spiral-inlet of two-pase separators respectively. Note that they are different in the inlet pipe to the Separator.

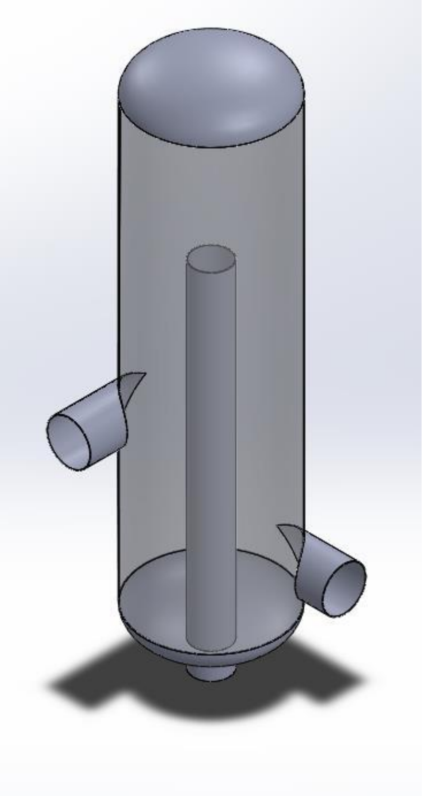

Figure 2. Bangma design separator [8]

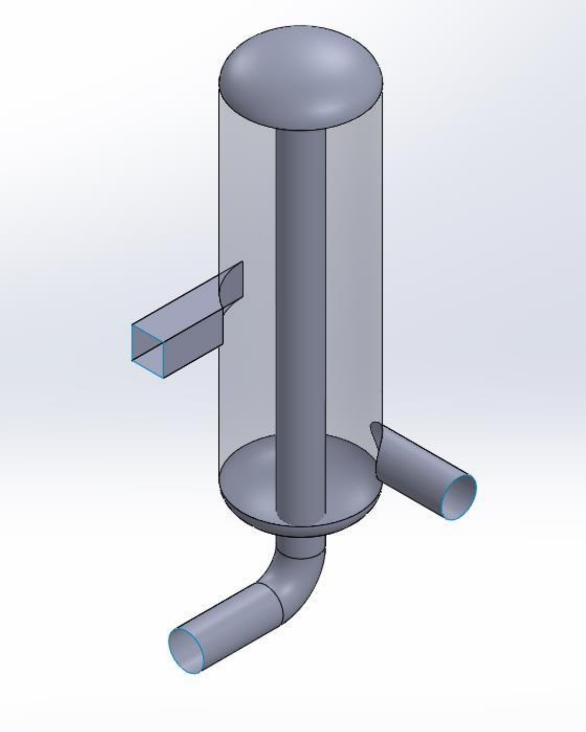

Figure 3. Lazalde-Crabtree Design Separator [8]

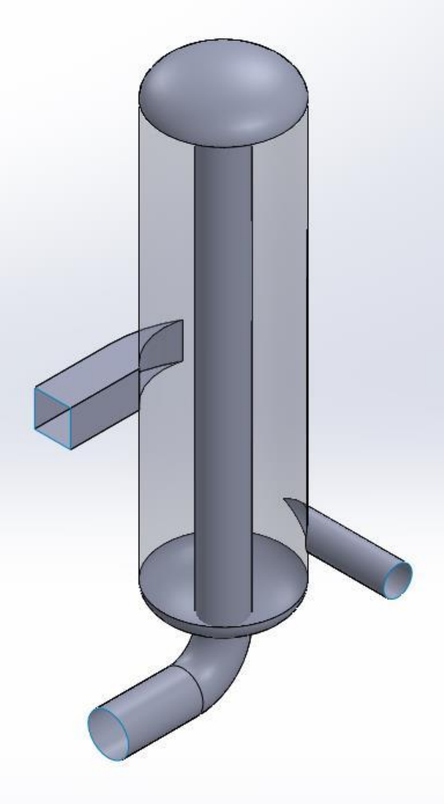

Figure 4. Spiral-inlet Design Separator [8]

Material Properties

The material for the Separator is SA-106 Gr. B, having allowable (design) stress of 14400 psi. Shell thickness is then calculated using the rule of the ASME Boiler and Pressure Vessel Code Section VIII Division 1 [9]. Under internal pressure of 1.355 MPa (196.52 psi) and inside diameter of 3.3 Dt [5], the minimum wall thickness is calculated as follows:

$$t = \frac{(196.52\,\text{psi})(114.46\,\text{in})}{2(14400\,\text{psi}) + 0.8(196.52\,\text{psi})} = 0.7875\,\text{in}$$

Adding corrosion allowance (CA) of 1/16 into this value, the thickness of the shell is 7/8 in (22 mm)

Element Type and Meshing

For the study of plastic limit load, SHELL281 element type from ANSYS element library was chosen. This element is a higher order 8 node element with six DOF per node, i.e., translation in the x, y, and z direction and rotation about the x, y, and z-axis. Figure 5 shows a typical finite element after meshing.

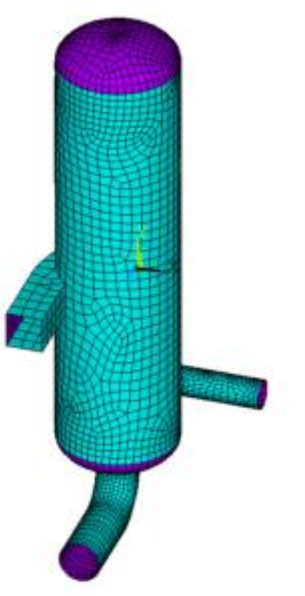

Figure 5. Typical finite element modeling

Nonlinear Solution

Before running the solution, boundary conditions and loading must be applied to the structures. Boundary condition is applied as a simulation of leg support for the vertical cylinder. Meanwhile, loading applied is internal pressure.

To obtain a limit load, an internal pressure of 3 MPa was applied as ramped. Limit load is the last convergence solution (less than 3 MPa) obtained using the nonlinear solution with the Newton-Raphson algorithm.

RESULTS AND DISCUSSION

Figure 6 shows the load-displacement curve for the separators designed using Bangma, Lazalde-Craptree, and Spiral Inlet (refer to Tables 1 and 2). It can be seen from Figure 6 that the Separator designed using the Bangma method results in a higher limit load compared to the Lazalde-Crabtree design and spiral-inlet design. A separator designed using a spiral inlet produces the lowest limit load. It can be read by close observation of Figure 6 that the limit load for Bangma, Lazalde-Crabtree, and Spiral-inlet was 2.339 MPa, 1.734 MPa, and 1.473 MPa respectively.

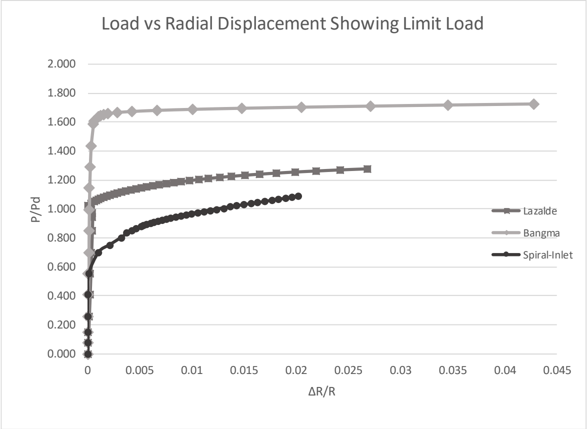

Figure 6. The load-displacement curve showing limit load comparison

It should be noted that the design method of Lazalde-Crabtree for two-phase separators is the most widely used separator design in geothermal power plants. The input pipe is welded in square form to the main shell. Spiral input is also welded in square form. However, the inlet pipe to the main shell is welded circularly for Bangma design and resulted in a higher limit load compared to Lazalde-Crabtree and spiral inlet.

Figure 7 shows the stress distribution for yield condition, plotted axially from the inlet pipe toward the top head of the Separator. It can be seen for the Bangma method that maximum stress is located at 1.18 $\sqrt{rt}$ from inlet and decay at 5.89 $\sqrt{rt}$. For both Lazalde-Crabtree and spiral-inlet designs, the maximum stress is located at the inlet. The stress decay at 4.78 $\sqrt{rt}$ for Lazalde-Crabtree method. For spiral-inlet design, the stress decay at 11.14 $\sqrt{rt}$.

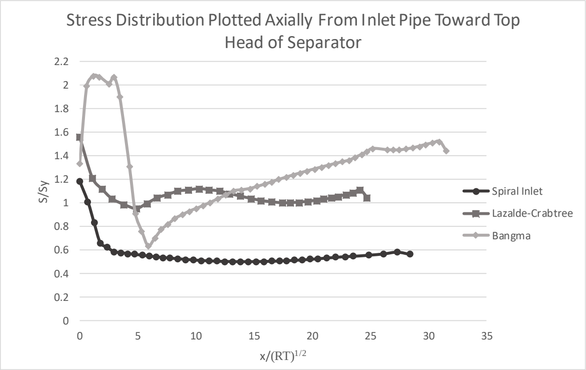

Figure 7. Stress distribution plotted axially from the inlet pipe to the top head of the Separator

Figure 8 shows the stress distribution at yield condition plotted circumferentially from the inlet pipe. It can be seen for the Bangma design that maximum stress is located at 2.53 $\sqrt{rt}$ and decay at 8.23 $\sqrt{rt}$. For the Lazalde-Crabtree design, maximum stress is located at 0.67 $\sqrt{rt}$ and decay at 6.13 $\sqrt{rt}$. For spiral-inlet design, maximum stress located at the inlet pipe and decay at 5.98 $\sqrt{rt}$.

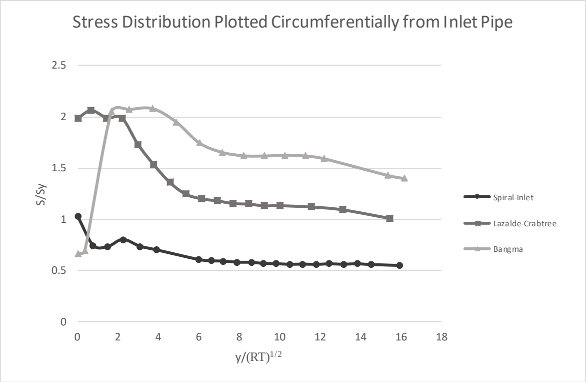

Figure 8. Stress distribution plotted circumferentially from inlet pipe

CONCLUSION

There are three methods to design a two-phase Separator for a geothermal power plant. i.e., Bangma, Lazalde-Crabtree, and Spiral inlet design. Results from the finite element study of these methods show that (1) the separator designed using Bangma method has higher limit load compared to lazalde-Crabtree and Spiral inlet, (2) maximum stress located at the intersection of the inlet pipe and main shell for the Separator designed using Lazalde-Crabtree and Spiral inlet, meanwhile, for Separator designed using Bangma method, maximum stress located at a certain distance from inlet pipe intersection with main shell, both axially and circumferentially.

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