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# Design With Solid works Software and Planning Calculation Analysis of Fire Tube Boiler With Lpg-Fuel For Oyster Mushroom Small Industries In Pacet, Mojokerto, East Java, Indonesia

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**ABSTRACT**: *Steam boilers (boilers) is a closed vessel made of steel that is used to generate steam. In the modern era many industries such as household scale industries for the manufacture of oyster mushroom spawn to use aid as a supplier of steam boilers are used as a sterilization process baglog. Annually, the number of requests oyster mushroom spawn have been increases, so the boiler is very significant equipment to increase the number of baglog production as oyster mushroom growing media.To help to fulfill the small industryrequiremets for oyster mushroom nursery,plannedatype offire tubeboilerthatcanhelpthe availability ofsteam ina lowscalewithsteamoutputcapacity of70kg/ h, temperature120℃, pressure1.5barandusingmaterialsLPGfuelas a source ofheatenergy.From the results of this design, fire tube boiler have efficiency of 0.934 % . The kettle body is made from asphalt drums pertamina with the Cold Rolled Steel materials. Used asphalt drums because of its availability in the market more easier to obtained easily and the dimensions of asphalt drum capable of holding for temperature and pressure have been determined . As for the pipe material using Carbon Steel Tubing Boilers ASME SA - 178A GRADE A / SA - 214 (Plain Carbon).*
**Keywords**: *Boiler, Fire-tube,Significant, Fuel,AsphaltDrum, Oyster Mushroom*

## I. PREFACE

Sterilizationof baglog as oyster mushroom mediais one of thevery important processinoystermushroom cultivationbecausethe mediahadcreatedusuallystill containsmanymicrobes, especiallywildmushrooms. Manycrop failurescaused bymediasterilizationprocessis less than perfect. Wildmushroomsthatstillexistinbaglogwill thriveandinhibitthe growth ofoyster mushroomif thesterilizationprocessis notperfect. Therefore tohelp to fulfill the small industry requiremets for oyster mushroom nursery, we are plannedatype offire tubeboilerthatcanhelpthe availability ofsteam ina lowscalewithLPGfuelas a source ofheatenergy.

In general, thekettleisoftenusedtoassist foodproductionisfire tubeboilertype. Becauseof the type offire tubeboilershaveseveraladvantages, ie. theconstruction is relativelymorerobust, lowmaintenance cost, easyoperationandmaintenance, constructionboiler-making process can be madeat thesmall workshopandthekettlehaveflexibilityinsettingandload changeduringoperation.

Boiler types comprises of fire tube, water tube, modular, coil tube and cast iron respectively. Steam boilers could be used for various services, such as, steam process and heating, hot water heating, power generation, petrochemical processes, chemical recovery, nuclear, just to mention a few[15]. Fire-tube boilers are safer to use, require less expertise, and operate under lower pressures than water-tube boilers. Thus, they are more suitable for small scale applications. Watertube boilers on the other hand, have a higher rate of steam production and are easier to construct and transport [8].

They are designed to withstand the stress induced in the boilers [12]. In a boiler, water is heated, steam is generated or superheated, or any combination thereof, under pressure or vacuum by the application of heat resulting from the combustion of fuel (such as in a natural gas boiler), electrical resistance heating or the recovery and conversion of normally unused energy [9].

Detailed theoretical analysis of the modified three pass dry back fire tube boiler was discussed and it was found from the feasibility study that the proposed model could be expected to produced continuous and constant steam input. It can be further expected to quicken the steam formation with higher efficiency and minimum water loses. This proposed modified boiler could be used in food processing units, textile units etc. with better productivity rates in future [2].

Based on the above issues and in terms of some of the results of research on fire-tube boiler, then in this paper will be discuss how to perform heat transfer calculations and to determine a fire tube steam boilers dimension planning with output capacity 70 kg / h, temperature 120 ℃ and pressure of 1.5 bar.

The purpose of this design is used to analyze the amount of heat transfer that occurs in the boiler and the size dimensions are obtained to determine a draft boiler. The results obtained from the data steam output capacity 70kg/h, temperature of 120 ℃ and pressure of 1.5 bar and to know the application of a fire tube boiler in SMEs oyster mushroom.

## II. METHODOLOGY

In this analysis and planning calculation, we will calculate the preliminary data previously retrieved and complete with supporting data , which will be obtained a dimension of fire tube boiler .

Below are the steps - steps of data collection and planning dimensional shape of a fire tube boiler . To clarify the flow of the final project and flow calculations and planning for fire tube boilers , can be seen in the picture below .

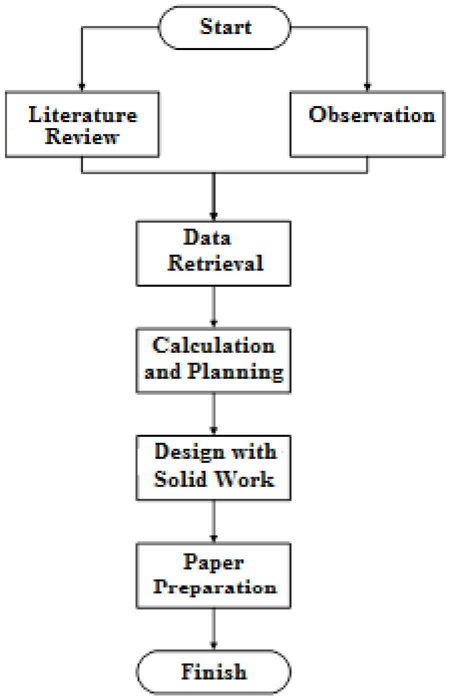


**Figure 1. Flowchart of Making Fire Tube Boilers**

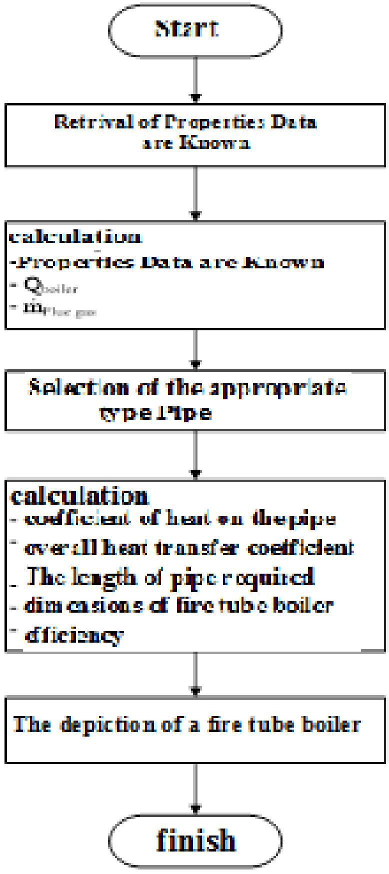


**Figure 2. Flowchart of Calculation and Planning for Fire Tube Boilers**

## III. RESULTS AND DISCUSSION

**Preliminary data are available :**

$\dot{m}_{steam}$ = $\dot{m}_{water}$ = 70 kg / hour = 0.01944 kg / sec
$T_{steam}$ = 120 ℃ = 393 ° K
$T_{water}$ = 30 ℃ = 303 ° K
$T_{burning}$ = 534 ℃ = 807 ° K
$P_{steam}$ = 1.5 bar

**III.1. Calculation of Heat Transfer**

From Table A – 2 [5]:

The incoming water temperature the boiler is 30 ° C thenthe price obtained for the enthalpy: $h_{inboiler}$ = 125.79 kJ / kg

From Table A – 4 [5,6]:

Temperature of 120 ° C and a vapor pressure of 1.5 bar at exit of the boiler then the price obtained for the enthalpy : $h_{outboiler}$ = 2711.4 kJ / kg

Heat required by the Fire Tube Boilers

$Q_{boiler} = m\ (h_{outboiler} - h_{inboiler})$
$Q_{boiler}$ = 50264.258 J / s

Analysis for $\dot{m}_{(flue\ gas)}$ and water average temperature absorbed ( $T_{cm}$ ).All data obtained from Table A - 4 [5] and Table A – 6 [5].

From Table A - 4 ( Air ) [5]:

$$T_{hm} = \frac{T_s + T_\infty}{2} = \frac{120 + 534}{2} = 327℃$$

The data obtained:

$$C_p = 1051 \frac{J}{kg.°K}$$
$$\mu = 305{,}8\ x10^{-7} \frac{N.s}{m^2}$$
$$k = 46{,}9\ x10^{-3} \frac{W}{m.°K}$$
Pr = 0,685

From Table A –6 ( Water ) [5].
Assumption average temperature (T_cm ) ≈ 80 ℃ = 353 ° K then the data obtained from interpolation as follows :

$$C_p = 4197{,}4 \frac{J}{kg.°K}$$
$$\mu = 351{,}8\ x10^{-6} \frac{N.s}{m^2}$$
$$k = 669{,}8\ x10^{-3} \frac{W}{m.°K}$$
Pr = 2,2

- Search ṁ_flue gas with the following equation :
  $$Q_{boiler} = Q_{flue\ gas}$$
  $$Q_{flue\ gas} = \dot{m}_{flue\ gas}.C_p.\Delta T$$
  $$\dot{m}_{flue\ gas} = 0{,}1155 \frac{kg}{s}$$
- Actual Proven average temperature absorbed by the water temperature is assumed :
  $$Q = \dot{m}_{flue\ gas}.C_p(T_{ci} - T_{co})$$
  $$T_{co} = \frac{Q}{\dot{m}_{flue\ gas}.C_p} + T_{ci}$$
  $$T_{co} = 406{,}68\ °K = 133{,}68\ ℃$$
  $$T_{cm} = \frac{T_{co} + T_{ci}}{2} = \frac{133{,}68\ ℃ + 30\ ℃}{2} = 81{,}84℃$$

  ( AssumptionsT_cm = 80 ℃ is fulfilled )

  The selection of pipes available in the market are taken with the following specifications :
  - Material = Carbon Steel Pipe Tubing Boilers ASME SA - 178A GRADE A / SA - 214 ( Plain Carbon )
  - Nominal Diameter = 3-1/2 " ( 11 GA )
  - Outside Diameter = 3.500 in = 88.9 mm = 0.0889 m
  - Pipe thickness = 0.120 in = 3.048 mm = 0.003048 m
  - Inside Diameter = 3.380 in = 85.852 mm = 0.085852 m

1. Flue Gas Flowing In The Pipeline
   $$Re_D = \frac{4.\dot{m}_{flue\ gas}}{\pi.D_i.\mu} = 56014{,}982$$
   Due to the turbulent flow correlation " Internal Convection Flow " using the equation :
   $$Nu_D = 0{,}023\ Re_D^{4/5} Pr^n$$
   $$Nu_D = 0{,}023\ Re_D^{4/5} Pr^{0,4} \longrightarrow n = 0{,}4 \text{ untuk heating}$$
   $$Nu_D = 124{,}350$$

   Then correlation " Internal Convection Flow " is :

   $$h_i = Nu_D.\frac{k}{D_i} = 67{,}931\ W/m^2.°K$$

2. Water Flow at Outside Pipe

$$Re_D = \frac{4.\dot{m}_{air}}{\pi.D_o.\mu} = 791{,}423$$

Due to the laminar flow correlation " External Convection Flow " using the equation :

$Nu_D = C\, Re_D^m Pr^{1/3}$ (C ~~and m~~ Data obtained in the equation constants table )

**Table 1. Constants Equation**

| $Re_D$ | C | m |
|---|---|---|
| 0,4 - 4 | 0,989 | 0,330 |
| 4 - 40 | 0,911 | 0,385 |
| 40 - 4000 | 0,683 | 0,466 |
| 4000 - 40000 | 0,193 | 0,618 |
| 40000 - 400000 | 0,027 | 0,805 |

$Nu_D = 0{,}683\ .791{,}423^{0{,}466}\, 2{,}2^{1/3}$

$Nu_D = 19{,}917$

$h_o = Nu_D.\frac{k}{D_o} = 150{,}061\ W/m^2.°K$

3. Conduction Happens In Pipe

Data Analysis for Carbon Steel Tubing Boilers ASME SA - 178A GRADE A / SA - 214 ( Plain Carbon ) obtained from Table A - 1 in the book " Fundamentals of Heat and Mass Transfer " price obtained is k = 48.0 W / ( m. ° K )

- conduction pipe:

  $\frac{r_i}{k}\ln\frac{r_o}{r_i} = 3{,}06879 \text{ x } 10^{-5}\ W/m^2.°K$

- Heat Transfer Coefficient:

  $U = \frac{1}{\frac{1}{konveksi\ \ internal} + konduksi\ \ pipa + \frac{1}{konveksi\ \ eksternal}}$

  U = $47{,}125\ W/m^2.°K$

- Dimensions Length Pipe:

  Pipe is considered a new pipe , so no fouling factor ( crust ) , then the length of the pipe :

  $\Delta T_{lm} = \frac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{\ln\left[\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}\right]} = 207{,}926$ ℃

  L = $\frac{Q}{U.\pi.D_i.\Delta T_{lm}}$ = 8,223 m

4. Fire Tube Boiler Efficiency

$$\eta_{thermal} = \frac{\dot{m}_{steam}\,(h_{out} - h_{in})}{\dot{m}_{flue\ \ gas}\, x\ LHV}\, x\ 100\%$$

$\eta_{thermal} = 0{,}934$ %

**III.2. Planning Design Fire Tube Boilers with Solid Work Software**

Dimensions of the data that have been obtained from the calculation , then the design of fire tube boiler can be designed into 3D and with the SolidWork software.

As well as the body material is also determined boilers and pipes that are used to plan a fire tube boiler . Here are the specifications of materials used for the body of the boiler and pipes in the boiler :

1. Boiler Materials:
   a. Cold Rolled Carbon Structural Steel Sheet ASTM A611 GRADE E
   b. Drum dimension :
      - Plate thickness = 0.6 mm
      - Drum length = 870 mm
      - Drum Diameter = 500mm
2. Pipe material in Boiler
   a. Carbon Steel Tubing Boilers ASME SA - 178A GRADE A / SA - 214 ( Plain Carbon )
   b. The dimensions of the pipe diameter
      - Nominal Diameter = 80 ( 10S )
      - Outside Diameter = 88.9 mm = 0.0889 m
      - Inside diameter = 85.852 mm = 0.085852 m

**III.2.1.Dimensions of Fire Tube Boilers**

Dimensions of Fire Tube Boilers can be planned from the total length of pipe that had been previously calculated. For the dimensions of Fire Tube Boilers planning can begin searching for :

1. Number of pipes

Number of Fire Tube Boilers Pipe

$= \frac{\text{Pipe length}}{\text{body length boiler}} = 12{,}273 \approx 12$ pipe

2. Plumbing Heating broad

The area of the heater on Fire Tube Boilers are :

The area of the heater = area x number of plumbing pipes

$= ((\pi \text{ x r x 2) x (t x r)) x 12}$

$= 99{,}811\ m^2$

3. Broad dimensions of the boiler body

Area of Fire Tube Boilers body dimensions are :

Broad dimensions of the boiler body = $((\pi \text{ x r x 2) x (t x r))}$

$= 263{,}108\ m^2$

4. Volume weight effectively unused boiler

Fire Tube Boilers body volume that is effectively used :

Boiler body volume = volume of water height x volume of boiler body

$= \frac{3}{4}\pi \text{ x } r^2 \text{x t}$

$= 98665644{,}28 mm^3$

5. The volume of water required to fill the boiler body

The volume of water required to fill the body of Fire Tube Boilers are :

- Total volume of heating pipe

  $= \pi \text{ x } r^2 \text{x t x number of pipe} = 49905619{,}62 mm^3$

- The volume of water in the boiler body

  = Volume of the boiler body - the total volume of heating pipe

  = 48,760,024.66 $mm^3$

6. Security analysis of drum boiler in terms of the comparison between the maximum capacity of internal pressure asphalt drum boiler with a predetermined pressure .

   Boiler body materials using bitumen drums with material **Cold Rolled Carbon Structural Steel Sheet ASTM A611 GRADE E.**

   - From the table Mechanical Properties of Steels Referred to in the 1996 AISI Specification will get the price Yield Strength of the material .

   Yield Strength ( Sy ) = 80 ksi = 552 MPa

   - Factor of Safety ( SF ) is determined from the type of load , type of material , type of stress , and the type of work that is being served . Because the boiler body material is made of stainless material and the expenses incurred on the fire tube boilers including static load / Steady Load . SF prices are obtained as follows :

Factor of Safety ( SF ) = 4

$$\text{Normal Stress } (\sigma) = \frac{Sy}{SF} = \frac{552\ MPa}{4} = 138 \text{ MPa}$$

7. Maximum internal pressure ofasphalt drum:

- Circumferential direction :

$$\sigma_1 = \frac{P.r}{t}$$

where:

r =radius of cylindrical body

t = thickness of the wall of the boiler body

P = internal pressure boiler

So,

$$P = \frac{\sigma_1 .\ t}{r} = \frac{138\ MPa \times 6x10^{-4}m}{0,25\ m}$$

= 0,3312MPa

= 3,312 Bar

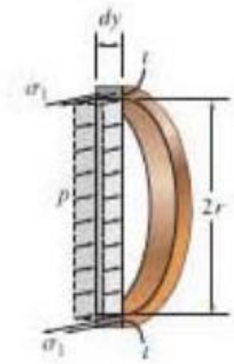


**Figure 3. Circumferential direction of asphalt drum**

- Longitudinal direction :

$$\sigma_2 = \frac{P.r}{2t}$$

$$P = \frac{\sigma_2 .\ 2t}{r} = \frac{138\ MPa \times 2x\ 6x10^{-4}m}{0,25\ m}$$

= 0,6624MPa

= 6,624 Bar

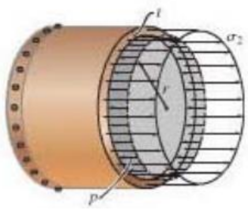


**Figure 3. Circumferential direction of asphalt drum**

From the calculation results can be proven that the boiler body made from asphalt drum is able to withstand circumferential pressure of 3,312 bar and a longitudinal pressure of 6.624 bar, while the pressure in the fire tube boiler that is planned at 1.5 Bar. It can be concluded that the asphalt drum made from **Cold Rolled Carbon Structural Steel Sheet ASTM A611 GRADE E** is safe to use for fire tube boiler design.

**III.2.2.1.Fire Tube Boiler Design in 3D**

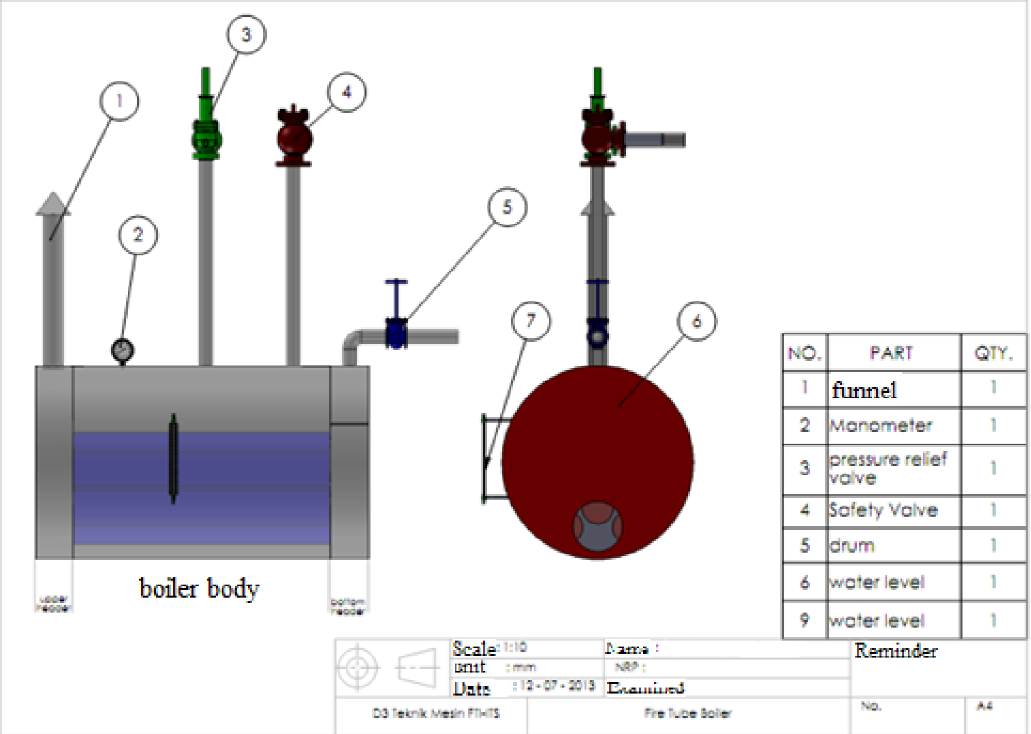


**Figure 5. Plan Design for Fire Tube Boilers**

**III.2.2.2.Fire Tube Boiler Design in 2D ( Pieces )**

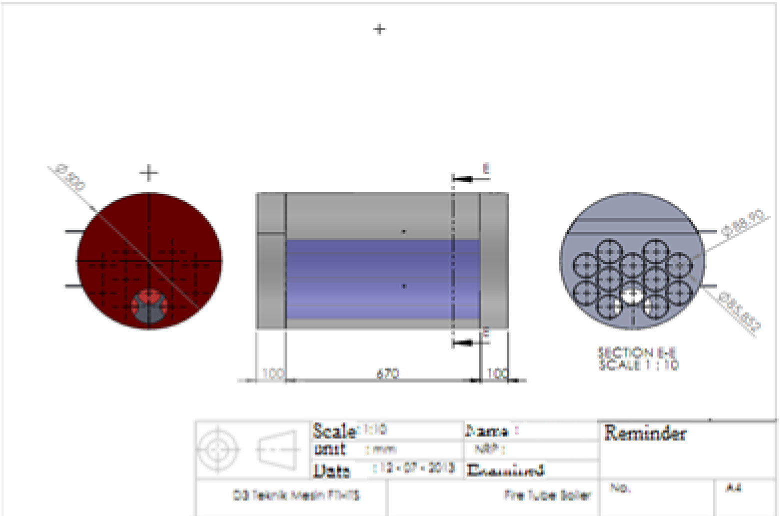


**Figure 6.Plan Design Dimensional for Fire Tube Boilers**

## III.3. Working Principle of Fire Tube Boilers

Fire tube boiler is a boiler where the flue gases of combustion are in the pipeline and water are in the outer wall of the pipe , so that the steam produced is outside the pipe . Its working principle is:

1. Water treatment from water tank entering the bottom header boiler through feedwater pump in the first passes through the water filter .
2. The water inbottom header and then enter the boiler and fill the space in between the outer wall of the pipe. While the flue gas from the furnace / Firebox passed into the pipes contained within the boiler . Because of the flue gas flowing inside the pipe and the outside wall of the pipe there is water , then the heat is located in pipe, most of heat were given to the water in the boiler. Thus, the effect of the water heating process turns into vapor.
3. After the phase change from water to steam in the boiler , the saturated steam exit from boiler through the distribution pipes. While the rest of flue gas that has passed through the pipes in the boiler are forwarded to the upper header and then discharged through the chimney.

## IV. CONCLUSIONS

From the analysis calculations that have been done then can be deduced:

1. The results of calculation of heat transfer of available data and the selection of pipes for fire tube boilers obtained results are displayed in the form of heat required by the boiler at 50264.258 J / s .
2. From the results of the calculation, the total length of pipe is 8.223 m , the number of pipes used as many as 12 pieces of pipe, Fire Tube Boilers body volume are used effectively by 98,665,644.28 $mm^3$ and the volume of water required to fill the body of Fire Tube Boilers 48,760,024.66 $mm^3$.
3. Based on the calculation of the efficiency of the fire tube boiler with LPG fuel obtained thermal efficiency of 0.934 %.
4. From the calculation of the maximum capacity of internal pressure on asphalt drum , with a circular pressure of 3.312 bar and a longitudinal pressure of 6.624 bar . It can be concluded that the asphalt drum safe for use as a fire tube boiler body with a capacity of 1.5 bar pressure .
5. Thefire tubeboilerunits, good enough tobe able toreplacesteaming equipmentona small industrialoyster mushroomsin particularsterilizationprocess.
6. Construction of fire tube boiler is very simple, so it is easy for maintenance .

## ACKNOWLEDGEMENTS

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