# STUDY OF BOILER CHARACTERISTICS

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## ABSTRACT

*Natural circulation boiler works on the principle of circulatory flow taking place because of density difference between two legs of the boiler. It works without employing any mechanical device and thus has less chance of tripping. It is known to be inherently safe and energy efficient mode of boiler operation. In view of its advantages, natural circulation is gaining ground in steam generation sector. The 300 MW Advanced Heavy Water Reactor being developed at Bhabha Atomic Research Centre in India is a natural circulation boiling water reactor (NCBWR). Use of natural circulation is very common in coal fired boilers also. With their increasing use, there is an urgent need to understand the dynamics of these types of boilers better. The natural circulation is one of the oldest principles for steam/water circulation in boilers. Its use has decreased during the last decades due to technology advances in other circulation types. Natural circulation principle is usually implemented on small and medium sized boilers. Typically the pressure drop for a natural circulation boiler is about 5-10 % of the steam pressure in the steam drum and the maximum steam temperature varies from 540 to 560 °C. In contrast to natural circulation boilers, forced circulation is based on pump-assisted internal water/steam circulation. The circulation pump is the main difference between natural and forced circulation boilers. Practically the maximum operation pressure for a forced circulation boiler is 190 bar and the pressure drop in the boiler is about 2-3 bar. Natural circulation boiler has been recognized as an economically and technically significant alternative with simple design and construction, high efficiency and intense mixing for heat and mass transfer, low power consumption, constant heat transfer areas independent of boiler load. Present work investigates the ongoing issues in boiler uses, calculating and evaluating different process parameters. Dynamics of Natural Circulation Boiler and characterization of heat transfer calculations is also studied.*

## INTRODUCTION

In India main source of power generation is Thermal energy, it's about 70% of the electricity generated by thermal power plant. In this power plants coal as burning fuel is used to produce large amount of steam to run the turbine. But the world electricity production shows the nuclear power generation plants now a day grown so much this provide almost 13.4% of the power generated [1].

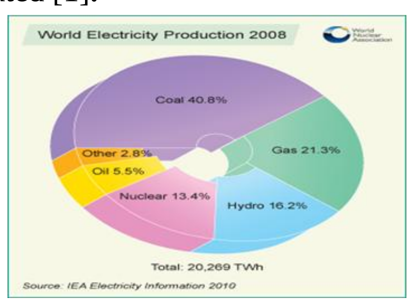



Fig 1.World Electricity Production

**Nuclear power,** electricity generated by power plants that derive their heat from fission in a nuclear reactor. Except for the reactor, which plays the role of a boiler in a fossil-fuel power plant, a nuclear power plant is similar to a large coal-fired power plant, with pumps, valves, steam generators, turbines, electric generators, condensers, and associated equipment.

Nuclear power provides almost 15 percent of the world's electricity. The first nuclear power plants, which were small demonstration facilities, were built in the 1960s. These prototypes provided "proof-of-concept" and laid the groundwork for the development of the higher-power reactors that followed.

The nuclear power industry went through a period of remarkable growth until about 1990, when the portion of electricity generated by nuclear power reached a high of 17 percent. That percentage remained stable through the 1990s and began to decline slowly around the turn of the 21st century, primarily because of the fact that total electricity generation grew faster than electricity from nuclear power while other sources of energy (particularly coal and natural gas) were able to grow more quickly to meet the rising demand. This trend appears likely to continue well into the 21st century. The Energy Information Administration (EIA), a statistical arm of the U.S. Department of Energy, has projected that world electricity generation between 2005 and 2035 will roughly double (from more than 15,000 terawatt-hours to 35,000 terawatt-hours) and that generation from all energy sources except petroleum will continue to grow.

In 2012 more than 400 nuclear reactors were in operation in 30 countries around the world, and more than 60 were under construction. The United States has the largest nuclear power industry, with more than 100 reactors; it is followed by France, which has more than 50. Of the top 15 electricity-producing countries in the world, all but two, Italy and Australia, utilize nuclear power to generate some of their electricity. The overwhelming majority of nuclear reactor generating capacity is concentrated in North America, Europe, and Asia. The early period of the nuclear power industry was dominated by North America (the United States and Canada), but in the 1980s that lead was overtaken by Europe. The EIA projects that Asia will have the largest nuclear capacity by 2035, mainly because of an ambitious building program in China.

**Objectives of Present Studies**

- To check adequacy of design.
- To determine actual steam generation capacity of boiler.
- To determine recirculation rate and vapor hold up for natural circulation boiler and compare it with values found in open literature values.
- To characterize resistance offered to recirculation flow in bottom of draft tube boiler.
- To determine overall heat transfer coefficient by experimental calculation and compare with theoretical calculation value.

**Experimental Set Up**

- **Process Flow Diagram**

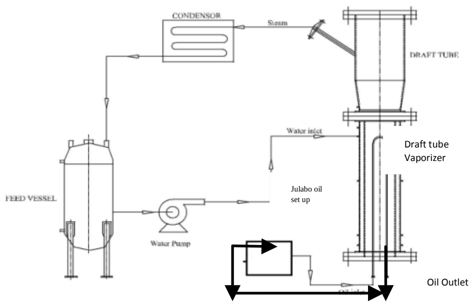



Fig 2. Process Flow Diagram.

- **Process Description**:

1) Water from feed vessel is fed to the draft tube vaporizer through water feed pump.
2) Draft tube vaporizers consist of two U tubes where heated oil is circulated through Julabo heating pump and the tubes are surrounded by water from feed vessel.
3) Due to heated oil, the water vaporizes and vapors are collected in a dome of draft tube vaporizer.
4) Then the vapors are transferred to the condenser where vapors are condensed due to continuous supply of cooling water to condenser.
5) Then the condensed water is fed to the feed vessel again. Thus the cycle continues again.

**Measured Variables**

- Temperatures on downcomer side- TI102,TI103,TI104
- Temperatures on riser side – TI105, TI106, TI107
- Feed water Temperature – TI101
- Vapor Temperature –TI121
- Hot oil supply Temperature –TI120
- Hot oil return Temperature –TI108
- Differential pressure in terms of mmH2O vapor side- DPT101
- Differential pressure in terms of mmH2O water side – DPT102
- Feed water flow rate – FI101

**Results and Discussions**

**1) Overall Heat Transfer Coefficient (Theoretical)**

**1.a) Adequacy of Design:**

The purpose of design calculations is to

Check the adequacy of the design.

**1. A.a) Heat Transfer Coefficient on OIL Side** [1.5]

Mass flow rate of oil ṁ= 0.1734kg/sec

Therefore velocity of oil is= (ṁ/ρA) = $\frac{0.1734\times4}{2\times840\times\pi\times0.0127^2}$= 0.82 m/sec

**Calculation Table**

| | | |
|---|---|---|
| Npr | Npr $= \frac{Cp\times\mu}{k}$ | 7.65E-04 |
| NRe | NRe $= \frac{D\times v\times\rho}{\mu}$ | 1041.4 |
| Nnu | Nnu $= 1.86\times(NRe\times Npr\times\frac{D}{L})^{\frac{1}{3}}$ | 0.325 |
| ho ,W/M2k | h $= \frac{Nnu\times k}{D}$ | 486.22 |

Table no.1 Individual Heat Transfer Coefficient hoil

Where D = 0.0127m

L = 1.89 m

**1. A.b) Heat Transfer Coefficient on Water Side** [1.5]

Grashoff co-relation can be written as,

$N_{Gr} = \frac{g*\beta*\Delta T*D3}{\gamma 3}$

Where,

1) $\beta = 1/T_F$

$T_F = (T_S + T\infty)/2 = 273* (168.109 + 97)/2 = 405.55K$

$\beta = 2.47E-03\ K-1$

2) Wall Temperature $T_S$

Heat due to heater = Heat transfer coefficient of oil side * Heat transfer area * (Toil – TS)

3 KW = 0.48622 * 0.1504 * (Toil – TS)

(Toil – TS) = 41

| | | |
|---|---|---|
| Npr | Npr $= \frac{Cp \times \mu}{k}$ | 6.45 |
| NGr | NGr $= \frac{g*\beta*\Delta T*D3}{\gamma 3}$ | 8.63E+06 |
| NRa | NRe $= NGr \times Npr$ | 55.66E+06 |
| Nnu | Nnu $= 0.15\,(NGr\ NPr)^{\frac{1}{3}}$ | 57.27 |
| hw ,W/M2k | h $= \frac{Nnu \times k}{D}$ | 2330.76 |

Therefore TS = 209.109 -41 = 168.109 $^0$C

**Calculation Table**

Table no.2 Individual Heat Transfer Coefficient hwater

Where g = 9.81 m/s2

Toil = 482.109 K

T∞ = 370 K

D = 1.72E-03 m

ΔT = (Toil – TR) = 70 K

**1.A.c) Overall Heat Transfer Coefficient U (Theoretical)** [1.5]

**Calculation Table**

| | |
|---|---|
| $\frac{1}{U} = \frac{1}{h\ oil} + \frac{1}{hw}$ | 0.00249 |
| U , W/M2k | 402.296 |

Table no.3 Overall Heat Transfer Coefficient U

**1. A.d) Adequacy of Design:** Adequacy of the design can be calculated by following co-relation. i.e. ΔTmin = ṁλ/UA.

Nominal steam generation capacity = 3 kg/hr.

Area of heat transfer installed = 0.15 m2.

With calculated U,

q = U A ΔTmin

ΔTmin = q/UA

= ṁ λ/ UA

= (0.00083*2260)/ (0.402*0.15)

= 31.21

Toil needed ≥ 132$^0$C

Julabo provided set point for Toil upto 300$^0$C

(ΔT) max = 200 $^0$C

And we required ΔT min = 31.21

Thus design is more than adequate.

**2) Steam Generation Capacity (Sample Calculation)**

Operating Condi: 1) Oil set point = 220$^0$C

2) Water flow rate = 2.5 kg/hr.

400ml condensate is measured at 8 min

therefore steam generation capacity is calculated as;

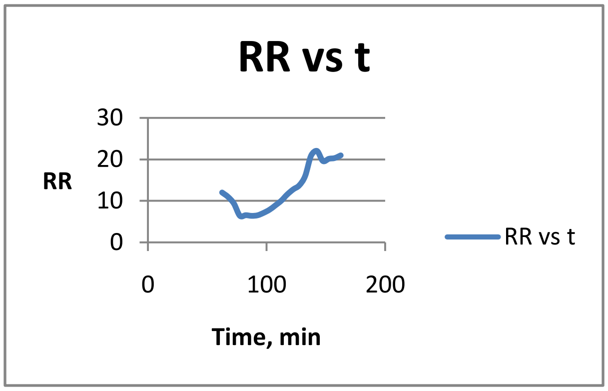
$$= \frac{400 \times 60}{8}$$

= 3000 ml/hr

= 3 lit/hr.

**3) Recirculation Rate**

"Recirculation rate is defined as the ratio of the mass of steam/water mixture to steam




generation." Recirculation rate is calculated above 0.8 m height, because above 0.8 m height only we get water recirculation. A point where water just mixes Or inlet water mixes with recirculated water to make downcomer water is called as mixing point.

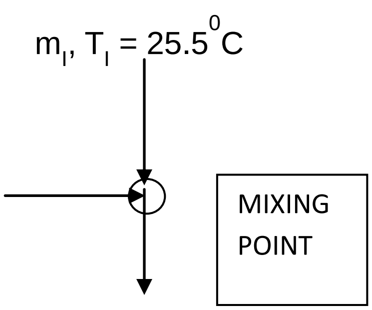
Energy balance around mixed point is,

$m_I T_I + m_R T_R = (m_I + m_R) T_D$

$m_R = m_I (T_D - T_I) / (T_R - T_D)$

$m_R = m_I (71 - 25.5) / (76.1 - 71)$

$m_R / m_I = 8.1$from Graph.RR VS



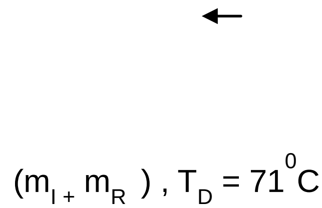




Fig 3 Energy Balance at Mixing Point for Recirculation Ratio

**4) Gas/Vapor Hold Up On Riser Side for Natural Circulation Boiler and Resistance Offered To Recirculation Flow in Bottom of Draft Tube Boiler**

**4.1)** Gas/Vapor Hold Up On Riser Side for Natural Circulation Boiler

Vapor hold up for natural circulation is calculated as,

VG = (ms/ρ)/A

Where ms = mass flow rate of vapor, kg/sec

ρ = density of vapor, kg/m3

A = Heat transfer area for draft tube, m2

VG = (4*1E-03)/(0.6 * 0.17*0.17*Π)

VG = 0.072 m/s

Therefor the gas hold up or fractional hold up on rising side is VG = 0.072m/s

Now Fractional Voidage is calculated as following formula,

$\epsilon = 0.5\,(VG)^{0.5} = 0.5\,(0.072)^{0.5}$---------[29]

= 0.1342.

**4.2) Resistance offered to recirculation flow in bottom of draft tube boiler.**

Since Recirculation Rate ranges between 5 – 20 we consider RR = 15 for further calculation

Let RR = 15.

$m_R$, $T_R = 76.1^0C$

Therefore,s

$RR = A_{RB}\,(H\,\epsilon)^{0.5}\,/\beta$

$\beta = 0.20003*(1*0.1342)^{0.5} / 15$

$\beta\ \ = 4.88E\text{-}03$

Now,

$$\beta = \frac{1}{\left(\frac{KR*(AR+AD)*\rho L*HD^{0.5}}{(mi)max}\right)}$$

$KR = (mi)max/(\beta(AR+AD)\ \rho L\ H_D{}^{0.5}$

$KR = 0.0012 / (4.88E\text{-}03(0.02269+0.01531) * 1000 * 1^{0.5})$

$KR = 6.45E\text{-}03$

**5) Overall Heat Transfer Coefficient (Experiment)**

**5.1) Overall Heat Transfer Coefficient U (Experiment)**

| Geometric dimension | Values |
|---|---|
| r, m | 0.0127 |
| Lu , m | 1.89 |
| N | 2 |
| Do ,m | 0.22 |
| L, m | 0.8 |
| ru,m | 5.11E-03 |

Table no 4 General Geometric Dimensions

**Calculation**

| | | |
|---|---|---|
| AH , m2 | $A_H = n * \Pi * r^2 * Lu$ | 0.1503 |
| H(AR+AD) = VL , m3 | $V_L = (\Pi D^2 L)/4 - (n \Pi ru^2 Lu)$ | 0.03033 |
| Toil , K | Toil = (TI108 + TI120)/2 | 297.5485 |
| TR , K | TR = (TI103 + TI106)/2 | 320.2196 |

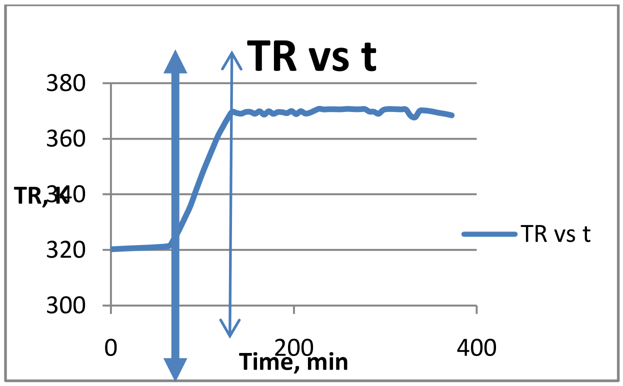
Table no.5 General Calculation

- **$T_{oil}$ Not Constant**

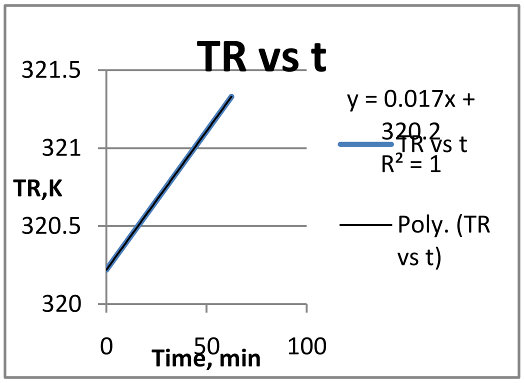
Operating Condi: 1) Oil set point = $220^0C$

2) Water flow rate = 2.5 kg/hr.

Plot TR VS t,




Now consider Region (from t=67.42 to 127.42.42 min),




Energy Balance Equation:

{Heat transfer through due Skin heater} + {Heat transfer to oil and water}

= Rate of Accumulation

$$2+U A_H (T_{oil} - T_R) = \rho_l Cp_l H(A_R+A_D)\frac{dTR}{dt}$$

Consider H(AR + AD) = VL

$$\frac{2+UAH(Toil-TR)}{\rho LCpLVL} = \frac{dTR}{dt}$$

$$\frac{2}{\rho L*CpL*VL} + \frac{UAH(Toil-TR)}{\rho L*CpL*VL} = \frac{dTR}{dt}$$

$$\frac{2}{1000*4.187*0.03033} + \frac{U*0.1504*(Toil-TR)}{1000*4.187*0.03033} = \frac{dTR}{dt}$$

$$0.01575 + 1.1844E\text{-}03 * U(Toil - TR) = \frac{dTR}{dt} \text{ ----------(1)}$$

Therefore,

$$U (1.1844E\text{-}03)(Toil - TR) = \frac{dTR}{dt} - 0.01575$$

From TR vs t graph we get,
TR = 0.7745t +269.73
Therefore,

$$TR' = \frac{dTR}{dt} = 0.7745$$

Putting TR' into equation (1) and Solving we get,
U* (1.1844E-03) (Toil - TR) = 0.7745 - 0.01575
U = (0.7745 – 0.01575/ (1.1844E-03 * 83.76125)
U = 7.6482 KJ/min M2k
U= 127.47 W/M2K

**Fouling Factor:**

Fouling factor is calculated by following Co-relation:

$$\frac{1}{U} - \frac{1}{UC} = Rd$$

$$Rd = \frac{1}{127.47} - \frac{1}{402.29}$$

Therefore Rd = 5.359E -03 m2 K/W

Conclusion: - According to the Experimental calculations, U = 127.47 W/m2 K which is lower than U calculated theoretically. We may explain this discrepancy as a result of possible scaling of heat transfer surface. It is to be noted that ordinary tap water was used for the experiment and pool of such water was maintained for long period around heat transfer surface.

## CONCLUSIONS

1) Julabo oil set up provided set point for Toil upto $300^0$C hence ($\Delta$T) max = 200 $^0$C and we required $\Delta$T min = 31.21 $^0$C.Thus design is more than adequate.
2) Steam generation capacity is reported as 3kg/hr. which tallies with plated capacity.
3) According to the literature survey, Recirculation Rate ranges between 5 – 25 [1.8] and the calculated recirculation rate is 8.1 which is within the range given by literature survey.
4) Gas or vapor hold up on riser side for

Natural circulation boiler is reported as 0.072 m/sec and Fractional Voidage $\epsilon = 0.1342$.

5) The Dimensionless resistance constant and constant in recirculation ratio is reported as $\beta = 4.88E-03$ and KR = 0.007.
6) According to calculation we get, OHTC (Theoretical) =402.29 W/m2K and OHTC (Experimental) = 127.47 W/m2K. Thus above mismatch might have happened due to scaling occurring in boiler.

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