**MINISTRY OF EDUCATION AND TRAINING**

**MINISTRY OF INDUSTRY AND TRADE**

**NATIONAL RESEARCH INSTITUTE OF MECHANICAL ENGINEERING**

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# "RESEARCH THE EFFECT OF SOME TECHNOLOGICAL PARAMETERS TO THE PRODUCTIVITY OF THE BOTTOM SLAG COOLING EQUIPMENT FOR CIRCULATING FLUIDZING BED BOILER"

MAJOR: MECHANICAL ENGINEERING
CODE: 62.52.01.03

## SUMMARY OF DISSERTATION OF DOCTOR OF ENGINEERING

**HANOI - 2017**

## LIST OF ANNOUNCED WORKS OF THE DISSERTATION

[1]. Hoang Trung Kien, Hoang Van Got and Nguyen Tien Sy, 2013. Research and propose the slag cooling method for CFB technology coal fired boiler in thermal power plants under the direction of reusing waste heat. *Science and Technology Journal*, Hanoi University of Industry, No. 17/ 08 2013.

[2]. Hoang Trung Kien, Hoang Van Got and Dao Duy Trung, 2014. Research and propose the bottom ash and slag cooling method for circulating fluidizing bed boiler. *The 15th ISPD 2014 "International Symposium on Eco-materials Processing and Design".*

[3]. Hoang Trung Kien, Nguyen Chi Sang, 2014. Research thermal exchange calculation model of the bottom ash cooling machine for circulating fluidizing bed boiler by dry method. *The 7th National Mechanical - Electronic Conference (VCM-2014),* Scientific works collection, Publishing House for Science and Technology.

[4]. Hoang Trung Kien and Hoang Van Got 2016. Research the effect of some main technological parameters to the productivity of tumbling machine-type slag cooling equipment for circulating fluidizing bed (CFB) boiler. *Vietnam Mechanical Journal*, No. 8 August 2016.

[5]. Hoang Trung Kien and Hoang Van Got, 2016. Research the effect of some main technological parameters to the productivity of rotating screw-type slag cooling equipment for circulating fluidizing bed (CFB) boiler. *National science and technology Conference on Mechanics - Motive force 2016.*

[6]. Hoang Trung Kien, Hoang Van Got and Tran Van Dich, 2017. Research the effect of some main technological parameters to the productivity of the bottom slag cooling equipment for CFB boiler by experiment. Vietnam Mechanical Journal, No. 9 September 2017.

## PREAMBLE

### 1. Necessity

The development direction using CFB boiler in Vietnam is suitable for taking full advantage of fuel which is low quality cola with big volume existing in coal exploitation regions. *However, the difficult issue often happens in production, that is trouble at the stage of bottom slag of CFB boiler through slag cooling equipment such as productivity is not stable due to many different reasons in which there is the reason of operation regime. Especially, as changing the firing coal fuel, it is necessary to select technological parameter set to operate suitably.* Such troubles cause direct effect, reduces the efficiency to the operation of boiler and the whole thermal power plant. The subject: "*Research the effect of some technological parameters to the productivity of the bottom slag cooling equipment for circulating coal fired boiler*" has urgent demand in coal-fired thermal power plants in Vietnam at present.

### 2. Objectives of dissertation subject

- Building the effect relationship of some main technological parameters to the productivity of slag cooling equipment;
- By theory and experiment, building the calculation method of heat exchange for the bottom slag cooling equipment for CFB boiler;
- Applying the research result of the dissertation into operation to improve the productivity and calculate the design of new slag cooling equipment, apply to the reality.

### 3. Scientific significance of the dissertation result

- Researched and selected the calculation method of heat exchange for the bottom slag cooling equipment on the basis of convection heat exchange process between the surface of machine wall and cooling water, heat conduction and heat radiation between hot slag and surfaces of machine wall. This is scientific basis for preparing the calculation model in service of design and operation of the equipment;
- By experimental research, built the relationship between output parameter namely cooling productivity and 3 main technological parameters: movement velocity of slag (v), cooling water discharge (q) and temperature of coolant namely water (t), then building the suitable parameter to improve the productivity of slag cooling equipment.

### 4. Reality significance of the dissertation result

- Applying main technological parameter set for operating the bottom slag cooling equipment for CFB boiler.
- Applying the calculation method of heat exchange for designing the bottom slag cooling equipment for CFB boiler of the unit 55 MW, achieved result proved scientific reliability and reality value.

- The calculation method can be used to serve the work of research and design for similar heat exchange equipment with different capacity.

**5. Research method**

- Research the theory in combination with experiment to determine the effect of 3 main technological parameters to the productivity of bottom slag cooling equipment for CFB boiler and apply the research result of the dissertation to the design, manufacture and operation of this equipment in reality condition of production for proving the reliability of research result;
- Use the method of orthocenal experiment planning to research the effect of 3 main technological parameters: cooling water discharge (q), temperature of cooling water (t) and movement velocity of slag (v) to the productivity of slag cooling equipment.

**6. New point of the dissertation result**

- The dissertation subject researched theory and carried out experiment on the bottom slag cooling industrial equipment for coal-fired boiler CFB in Vietnam to determine the effect of 3 main technological parameters to the productivity of the bottom slag cooling equipment for CFB boiler;
- Researched and selected the calculation method of heat exchange on the basis of mixed process: *convection heat exchange, heat radiation and heat conduction*, the result was applied, checked in designing, manufacturing a screw-type slag cooling equipment, applied to the production reality, achieved the result with high reliability and stability.

**7. Limitation of the dissertation**

The dissertation only limits the research, determination of heat transmission model of screw-type slag cooling equipment as the basis for building the design calculation method to research the effect of some main technological parameters: cooling water discharge (q), temperature of cooling water (t) and movement velocity of slag (v) to the productivity of bottom slag cooling equipment for CFB boiler by experiment.

**8. Object of research**

Applying the calculation method, design and manufacture of screw-type bottom slag cooling equipment for CFB boiler and researching the effect of some main technological parameters: cooling water discharge (q), temperature of cooling water (t) and movement velocity of slag (v) to the productivity of equipment by experiment.

# CHAPTER 1:
# OVERVIEW OF BOTTOM SLAG COOLING AND COLLECTION TECHNOLOGY FOR BOILER IN COAL-FIRED THERMAL POWER PLANT

## 1.1. Research situation of the bottom slag collection technology for coal-fired boiler in thermal power plant in the world

### 1.1.1. General diagram of ash and slag collection system of the coal-fired thermal power plant

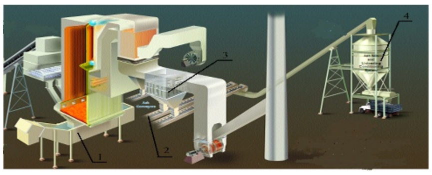


Figure 1.1: General diagram of ash and slag collection system of the thermal power plant

**1.1.2. Classification of ash and slag disposal technology [27], [30] (figure 1.2):**

**1.2. Some types of heat exchange equipment**

**1.3. Situation of researching the bottom slag cooling method for CFB boiler in Vietnam and in the world**

**1.3.1. Situation of researching and applying the bottom slag cooling method for CFB boiler in Vietnam**

**1.3.2. Some new scientific works in the world on the bottom slag cooling method for CFB boiler**

- Authors: B.Zeng, X.F. Lu, H. Z. Liu (2016). Industrial Application study on New type Mixet - Flow Fluidized Bed Bottom Ash Cooler [30]: The works tested a type of slag cooling equipment by dry method, having mechanism of preventing from creating slag crumbling, increasing the cooling productivity.

- Group of authors: Wei Wang, Xiaodong Si,.. (2013). (Heat-Transfer Model of the Rotary Ash Cooler Used in Circulating Fluidized-Bed Boilers). Researched heat-transfer model of rotary bottom ash cooler for CFB boiler. By experiment, it proved that *heat transfer coefficient between slag - air and air - water is approximately equal and much smaller than heat transfer coefficient between slag - water.*

**Comment:** From the analysis of ash and slag cooling works in the world, it shows that:

- Cooling by dry method can be by air or by indirect water or coordinated both coolants;

- The heat transfer coefficient between slag and water is the biggest in comparison to the transfer coefficient - screw-type cooling equipment has more dominant advantage that rotary drum type.

The works in the world have not researched the effect of three main technological parameters (q), (t) (v) to the productivity by fired coal in Vietnam.

**1.3.3. Screw-type slag cooling equipment for boiler**

*1.3.3.1. Structure of screw-type slag cooling equipment (H.1.15)*

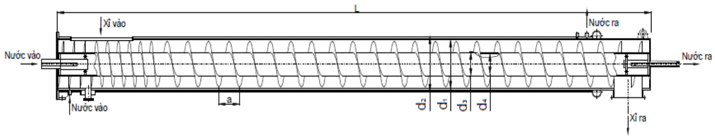



Figure 1.15. Structure of screw-type slag cooling equipment

## 1.4. Selecting type of the bottom slag cooling equipment for CFB boiler

### 1.4.2. Selecting the slag cooling equipment and heat exchange model

- Research object of the dissertation subject: *screw-type cooling equipment, pipe sleeve structure type*

- Model of heat transfer process: *combining convection heat exchange, heat radiation and heat conduction.*

**CONCLUSION OF CHAPTER 1**

1. Researched the overview of some slag cooling methods by heat exchange equipment such as

- Dry method, cooling slag by indirect water or by cool air, cooling according to dry method has ability to re-use the waste heat. The method by air has not been applied in Vietnam;

- Wet method, hot slag is soaked in the water as cooling and the slag after being cooled is in the mixed state with water, cooling according to wet method has ability to cool quickly but the equipment occupies much area, causes environmental pollution, waste ash and slag are in wet state, suitable for spraying (PC technology boiler);

2. Selected the research object which is screw-type bottom slag cooling equipment for CFB boiler, one itinerary, it is heat exchange equipment having screw body which is one-layer cylinder, structure of equipment type “pipe sleeve”;

3. Model of heat transfer process is *the combination of convection heat exchange, heat radiation and heat conduction*. This is the basis for chapter 2 selection of calculation method of heat exchange and determination of the productivity of slag cooling.

# CHAPTER 2:
# THEORETICAL FOUNDATION OF HEAT EXCHANGE PROCESS IN SLAG COOLING EQUIPMENT

2.1. Operation principle of screw-type slag cooling equipment

2.2. Selection of calculation method of heat transfer for slag cooling equipment

a, *Determine type of slag making equipment:* type “pipe sleeve”, single itinerary

b, *Forms of heat exchange in slag cooling equipment: convection heat exchange, heat radiation and heat conduction* [6], [36], [38].

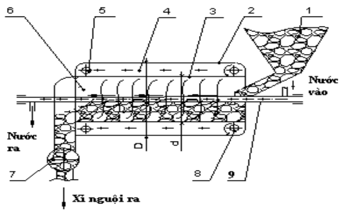



Figure 2.1 Principle diagram of the bottom slag cooling equipment for boiler by indirect water

**2.3. Factors affecting to heat exchange in cooling equipment**

**2.4. Theoretical foundation of heat exchange in the slag cooling equipment of type "pipe sleeve"**

**2.4.1. Forms of heat transfer in slag cooling equipment**

2.4.1.1. Concept of *mixed heat transfer (TDNHH):*

2.4.1.2 Convection heat transfer

*a, General concept [2], [4], [6]*

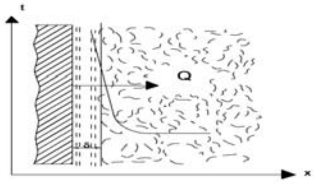



Figure 2.2: Model of heat change in edge layer as the liquid absorbs heat [4],

*2.4.1.2. Set of equations of convection heat exchange (TDNDL)*

*a) Newton law on convection heat exchange [4]*

$$q = \alpha \Delta t = \begin{cases} \alpha (t_f - t_w) khi t_f > t_w \\ \alpha (t_w - t_f) khi t_w > t_f \end{cases} \tag{2.4}$$

*b) Set of equations of convection heat exchange*

- *Heat transfer equation:* $\alpha = -\dfrac{\lambda}{\Delta t}\left(\dfrac{\partial t}{\partial n}\right)_{n=0}$ (2.5)

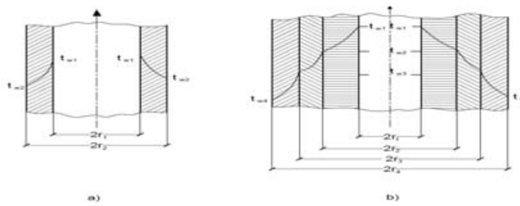
**2.4.2. Foundations of determining coefficient of convection heat exchange (TDNDL) by experiment**

*2.4.2.1, Similar theory [4], [6], [22]*

**2.4.3. Heat transfer through cylinder wall of heat exchange equipment [2], [4], [37], [39]**

*a, Calculation of heat flow transferred through cylinder surface*

$$\frac{d^2t}{dr^2} + \frac{1}{r}\frac{dt}{dr} = 0, r_1 \le r \le r_2 \tag{2.22}$$




a) One-layer cylinder wall; b) Multi-layer cylinder wall

Fourier law on density of heat flow on 1 $m^2$ of isothermal surface:

$$q = \lambda \frac{t_{W1} - t_{W2}}{\ln \frac{r_2}{r_1}} \frac{1}{r} \quad (2.26)$$

*b, Heat flow through cylinder wall:* heat flow Q transferred through a cylinder surface with radius r

$$Q = Fq = (2\pi r l)\lambda \{ \frac{t_{W1} - t_{W2}}{\ln \frac{r_2}{r_1}} \frac{1}{r} \} = 2\pi l \lambda \frac{t_{W1} - t_{W2}}{\ln \frac{r_2}{r_1}} \quad (2.27)$$

Length 1 of one- layered cylinder wall:

$$q_1 = \frac{Q}{1} = \frac{t_{W1} - t_{W2}}{\frac{1}{2\pi\lambda} \ln \frac{r_2}{r_1}} = \frac{t_{W1} - t_{W2}}{\frac{1}{2\pi\lambda} \ln \frac{d_2}{d_1}} \quad (2.28)$$

If the cylinder wall includes n layers:

$$q_1 = \frac{t_{W1} - t_{W2}}{\frac{1}{2\pi\lambda_1} \ln \frac{d_2}{d_1}}; q_1 = \frac{t_{W2} - t_{W3}}{\frac{1}{2\pi\lambda_2} \ln \frac{d_3}{d_2}}; ...q_1 = \frac{t_{W(n+1)} - t_{Wn}}{\frac{1}{2\pi\lambda_n} \ln \frac{d_{n+1}}{d_n}} \quad (2.29)$$

### 2.4.4. Calculating temperature of surface of two walls of cylinder cooler [4], [7], [35]

Suppose to have a cylinder wall (figure 2.4) length L, inner diameter $d_1$, outer diameter $d_2$, coefficient of heat conduction λ. Hot liquid has temperature $t_{f1}$ moving inside the pipe, cold liquid has temperature $t_{f2}$. Specific heat $q_L$ has form (2.31):

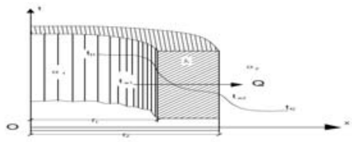


Figure 2.4: Model of heat transfer through cylinder wall

$$\left.\begin{aligned} \frac{Q}{L} &= q_L = \alpha_1 \pi d_1 \left(t_{f1} - t_{w2}\right) \\ q_L &= \frac{2\pi\lambda\left(t_{w1} - t_{w2}\right)}{\ln \frac{d_2}{d_1}} \\ q_L &= \alpha_2 \pi d_2 \left(t_{w2} - t_{f2}\right) \end{aligned}\right\} \quad (2.31)$$

For wall with many layers, we have:

$$\frac{1}{k_L} = \frac{1}{\alpha_1 d_1} = \sum_{i=1}^{n} \frac{1}{2\lambda_i} \ln \frac{d_{i+1}}{d_i} + \frac{1}{\alpha_2 d_{n+1}} \quad (2.36)$$

$$\frac{1}{k_L} = \frac{1}{\frac{1}{\alpha_1 d_1} + \sum_{i=1}^{n} \frac{1}{2\lambda_i} \ln \frac{d_{i+1}}{d_i} + \frac{1}{\alpha_2 d_{n+1}}} \quad (2.37)$$

Temperature of 2 unknown cylinder wall is: $t_{w1}$ and $t_{w2}$ under (2.38):

$$t_{w1} = t_{f1} - \frac{q_L}{\pi} \frac{1}{\alpha_1 d_1} \text{ and } t_{w2} = t_{f2} - \frac{q_L}{\pi} \frac{1}{\alpha_2 d_2} \quad (2.38)$$

**2.5. Theoretical foundation of heat radiation**

**2.5.1. Radiation flow, radiation productivity and radiation strength [4], [38]**

- *Radiation productivity:* $E = \frac{dQ}{dF}$ (2.39) - *Radiation strength is radiation productivity corresponding to a narrow space of wave length:*

**2.5.2. Specific radiation productivity and useful radiation productivity [4], [38]**

- Useful radiation productivity Ehd is total specific radiation productivity E and reflex radiation productivity ER of object.

$$E_{hd} = E + E_R = E + (1-A)\, E_t \quad (2.47)$$

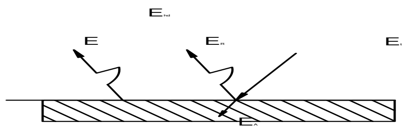



Figure 2.5: Diagram of model of calculating productivity of heat radiation

**2.5.3. Grey object**

**2.5.4. Radiation heat exchange between two objects covering each other [4], [38]**

Outer covering object has surface area $F_2$, absorption coefficient $A_2$ with unchanged temperature $T_2$. Covering object is convex object with area $F_1$, absorption coefficient $A_1$ with unchanged temperature $T_1$ during the heat transfer ($T_1 > T_2$) (figure 2.6).

Definition: convex object is object which all radiation arrays at a point on its surface cannot reach it

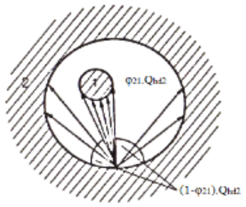



Figure 2.6: Diagram of heat radiation as two objects cover each other

Call radiation coefficient of the second object to the first object $\varphi_{21}$ as ratio:

$$\varphi_{21} = \frac{Q_{21}}{Q_2} \tag{2.50}$$

If $Q_{21}$ is radiation part to the first object, the remaining part of the radiation of the outer covering object to it is $(1-\varphi_{21})$, $Q_2$. The useful radiation of two corresponding objects is:

$$Q_{hd1} = Q_1 + (1 - A_1)\varphi_{21} Q_{hd2} \tag{2.51}$$

$$Q_{hd2} = Q_2 + (1 - A_2)Q_{hd1} + (1 - \varphi_{21})(1 - A_2)Q_{hd2} \tag{2.52}$$

**Comment:** Hot slag in the screw-type cooling drum is covered by drum case of screw body. Therefore, the calculation of heat transfer due to radiation needs to apply the theoretical part of radiation between two objects covering each other.

### 2.6. Calculation of necessary heat quantity to meet the productivity of heat exchange equipment

#### 2.6.1. Heat quantity transferred between two coolants [6], [37]

Fourier law, relationship between transferred heat quantity and heat exchange condition:

$$Q = -\lambda \int_F \mathrm{grad}\, t_f \, dF \tag{2.60}$$

Newton formula:

$$Q = \alpha F (t_f - t_w), \ \mathrm{W} \tag{2.61}$$

- F - Heat exchange surface;
- $\Delta t = (t_f - t_w)$: temperature difference (where: $t_f$ - liquid temperature, $t_w$ - temperature of wall surface);
- $\alpha$ - Heat emission coefficient:

$$\alpha = \frac{dQ}{(t_f - t_w)dF} = \frac{q}{t_f - t_w}, \ \mathrm{W/m^2}. \tag{2.62}$$

Heat emission coefficient $\alpha$ depends on many factors, can be shown in form:

$$\alpha = f(t_f, t_w, \omega, \lambda, c_p, \rho, \mu, \varphi, l_1, l_2, l_3,...) \quad (2.63)$$

**2.6.2. Absorption or emission heat quantity of coolant [4], [37]**

Productivity of the heat exchange equipment $G_i$, heat quantity q needs absorbing or emitting of the coolant:

$$q = G_i . C_i (t_1^{'} - t_1^{''}) \quad (2.64)$$

**Comment:** Like this, the productivity of heat exchange equipment of the coolant depends on the difference of **temperature of two coolants (t), movement velocity of coolant (v) and output of coolant (q).** Mathematics relationship (f = (t, v, q) is objective put forth by the dissertation.

**CONCLUSION OF CHAPTER 2**

1. Researched the theory and showed some basic factors affecting to heat exchange in the slag cooling equipment: density difference of fluid or external force to the flow, movement regime of fluid "layer flowing" or "tangled flowing", physical property of fluid, feature of heat exchange surface.
2. Researched the theory and withdrew the mathematics relationship, determined the heat flow Q in the one-layer cylinder wall heat exchange equipment (formula 2.27). This is important foundation to apply the calculation of heat exchange area for screw-type slag cooling equipment.
3. Withdrew the mathematics relationship (formulas 2.61, 2.62, 2.63, 2.64) between **productivity** of heat exchange equipment and some main technological parameters of coolant such as temperature difference of two coolants **(t)**, movement velocity of coolant **(v)** and emitted/absorbed heat quantity of coolant **(q)**. This is theoretical foundation for researching by experiment in chapters 3, 4.
4. Process of screw-type cooling equipment, structure of *pipe sleeve form* with screw body in cylinder form is form of heat exchange: *combination between heat convection, heat radiation and heat conduction.* This is scientific foundation for calculating the design of equipment in the next chapters.
5. The bottom slag cooling equipment for boiler works in the conditions of high temperature and attrition bearing, as design, manufacturing, there must be technical and technological solution to meet the severe condition.

# CHAPTER 3:
# MATERIALS, EQUIPMENT AND METHOD OF RESEARCH

**3.1 Condition of testing margin**

- Cooling water output, q: $m^3$/minute: [0.25 - 0.35];
- Rotary velocity of drum, revolution: rpm [0.8 - 1.4];
- Temperature of cooling water, t: C: [29$^o$C - 33$^o$C].

**3.2 Testing material**

The material is slag of dust coal 5b Hon Gai Vietnam [21], has medium grain size of 5mm, temperature of hot slag is: 900$^o$C [21], [18], [19], Cold coolant is water (temperature: 29 - 33$^o$C), output: (0.25 - 0.35 $m^3$/minute), water pressure: p = 0.6 MPa.

**3.3. Testing equipment**

**3.3.1 Measurement equipment**

*a, Endress Hauser electromagnetic water output meter (Federal Republic of Germany)*

Figure 3.1: Output meter according to electromagnetic principle Endress Hauser

*b, Thermocouples:*

Equipment sign: Omron E52MY Series thermocouples used for measuring the temperature directly up to 1300°C, equipped at the production line at the Company, meets the experiment requirement

Figure 3.4: Equipment principle of Omron E52MY Series firm


Figure 3.4: Structure diagram of thermocouples

3, Velocity meter: Omron E3F-DS10C4 (figure 3.5):

Rotary velocity of screw axis, the time as sensor receives the impact will be interpolated the velocity (m/s) measured at actual time.

Figure 3.5: Image of structure of installing sensor for measuring rotary velocity of axis

**3.3.2. Testing model**

*Equipment description:* [7] The testing model is bottom modern industrial slag cooling equipment for screw-type circulating coal fired boiler, the technical parameters are described on figure 3.7:

**3.3.2. Model of testing equipment on figure 3.7. [31]**

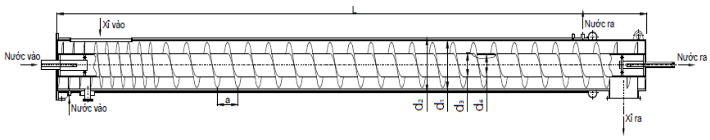



Figure 3.7: Modelizing screw-type industrial slag cooling equipment

### 3.4. Method of determining technological parameters

#### 3.4.1 Determining cooling water output

There are two methods:

*a) Direct measurement method:* by water output meter at the pipeline supplied to machine;

*b) Theoretical calculation:* Theoretical water output:

$$q = vs, \ m^3/h \quad [59]$$

#### 3.4.2. Determining slag transport velocity in cooler

There are two methods:

a) Direct measurement method: Using velocity meter

b) Theoretical calculation method: Rotary velocity of screw axis:

$$n_t = n_d \, i_g \, i_x \, [58] \qquad (3.1)$$

Velocity of electric motor: $n_d$, transfer ratio of speed reduction: $i_g$ and transfer ratio of chain driver $i_x$

#### 3.4.3. Determining the temperature of incoming and outgoing slag in the cooler

Measure directly by thermocouples at two positions: enter door and exit door, take average value [7].

#### 3.4.4. Determining the slag cooling productivity

There are two methods:

*3.4.4.1. Determining the productivity by experiment on level measurement equipment [7]:*

Level measurement means *measurement of height of slag layer in silo* by automatic level measurement system, level measurement by sensor, level measurement by radar: Productivity of cooler: $G_x = \gamma \pi h D^2/4$. Where: D - diameter of silo; ($\gamma$) - Specific volume of slag is determined by testing. General diagram of system for transporting slag to silo and arranging the level measurement equipment (figure 3.8). [31].

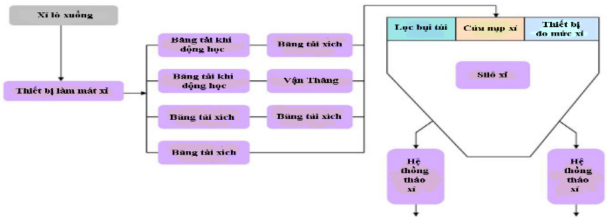



Figure 3.8: Diagram of collecting and transporting the bottom slag of CFB boiler to storage silo

Formula of level calculation (a) of powder coal slag in the silo system:

$$a = \frac{tc}{2} \qquad (3.4)$$

Where: t means total time of $t_1$ and $t_2$, $t_1$: means as the reflex is satisfied after the wave is transmitted; $t_2$: means the time as signal reflexes to measurement equipment.


Figure 3.11: Handheld level measurement equipment and PDM software

*4.4.4.2. Productivity calculated under theory:*

*Gx = πd2/4 naψγ, ton/h*

Where: d - Screw diameter, m; a - Screw step, m; n - Rotary velocity of screw, rpm; ψ - Filling coefficient of screw, for cooler, maximum 50%

γ - Specific volume of slag, ton/$m^3$ heap status

**3.5. Method of experiment of data processing [9], [12], [16]**

**3.5.1 Method of experiment planning**

**3.5.2 Square minimal method**

Using square minimal method, with the objective of selecting type of square multinomial function of variables with square 3-variable function, there are two types [9], [12]:

$$G(q,v,t) = a_1 + a_2 q + a_3 v + a_4 t + a_5 qv + a_6 qt + a_7 vt + a_8 q^2 + a_9 v^2 + a_{10} t^2 \tag{3.10}$$

Regression functions are found according to error square minimal law:

$$P = \sum_{i=1}^{27}\left[G_i - G(q_i, v_i, t_i)\right]^2 = \sum_{i=1}^{27}\left[G_i - \begin{pmatrix} a_1 + a_2 q_i + a_3 v_i + a_4 t_i + a_5 q_i v_i + a_6 q_i t_i \\ + a_7 v_i t_i + a_8 q_i^2 + a_9 v_i^2 + a_{10} t_i^2 \end{pmatrix}\right]^2 \tag{3.11}$$

Where $G_i, q_i, v_i, t_i$ , are values of each known point in experiment table;

$a_1, a_2, ..., a_9, a_{10}$ are variables to be found.

Equation (3.10) is called as regression function. Number of test N to be implemented as QHTN calculated under: N = $3^k$ (k = 3) = 27; k: Number of research factor; G: Output parameter.

**3.5.3 Checking the efficient significance level and adaptability of mathematical model [12]**

1) Checking the significance level of regression coefficient under STUDENT standard

Variance of regression coefficients [3]

$$S_b = \sqrt{\frac{S_y^2}{N}} \tag{3.12}$$

The coefficient of regression is meaningful when $|b| \geq S_b t$, (t coefficient of STUENT)

In which:

2) Checking the meaningfulness of the regression function according to Fisher norm[12]

$$F_b = \frac{\max(S_{ag}^2, S_y^2)}{\min(S_{ag}^2, S_y^2)}$$

**3.5.4 Experiment steps [50]**

*Step1*: Initial experiment conducted to check whether the objective function has been in the surrounding area of the extreme zone or not.

**CONCLUSION OF CHAPTER 3**

1. Selected the experiment equipment including: The applicable experiment model is the bottom slag cooling equipment for modern industrial CFB together with the modern measuring instrument such as the throttle meter lFD613 of Omega branch in The USA, temperature meter FT 1300 - 2; speed meter: Omron E3F-DS10C4 and leveling equipment Sistrans LR 260 of Siemen to define the productivity.

2. Determined the experiment condition: cooling water flow, (q) $m^3$/ph:[0,25 – 0,35], spinning speed of the screw, (v) vg/ph [0,8-1,4]; temperature of cooling water (t): [29$^o$C- 33$^o$C].

3. Already adopted the experiment step which was the initial, climbing experiment to search for the extreme zone and conduct the experiment by experimental planning method for optimization.

4. Selected the experimental planning method to set up the mathematic relationship between 3 major parameters: slag movement speed (v), temperature of cooling water(t) and the cooling water flow (q) with the output which is the productivity ($G_x$) of the slag cooling equipment equivalent to the applicable temperature limit of output slag of ≤ 170$^o$C.

CHAPTER 4:
THE EXPERIMENT TO DETERMINE THE EFFECT OF SOME MAJOR TECHNOLOGICAL PARAMETERS TO THE PRODUCTIVITY OF THE SLAG COOLING EQUIPMENT AND ITS APPLICATIONS TO PRACTICAL PRODUCTION

**4.1. Experiment and processing the experiment data**

**4.1.1. Experiment preparation**

: q $m^3$/ph:[0,25 - 0,35]; vg/ph: [0,8-1,4]; t: [29$^o$C - 33$^o$C], set the water flowing direction same as the moving direction of hot slag.

**4.1.2. Experiment**

The testing method is the parallel testing.

*Regression function:* The productivity equation describes the dependence on 3 general technological parameters:

$$G_x = f(x_1, x_2, x_3) = f(q, v, t) \quad (4.1)$$

**4.2. Processing experiment data**

$G_{tn}$ – experiment productivity; $G_{tt}$ – calculation productivity from quadratic mathematic model;

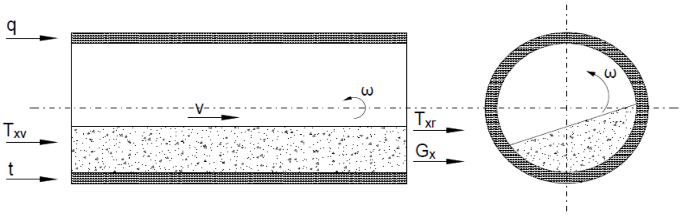
e – the difference between $G_{tn}$ and $G_{tt}$ by percentage (%): $e = \frac{|G_{tt} - G_{tn}|}{G_{tn}} 100\%$ (4.2)

Objective function: Productivity: $G_x$ = f(q,v,t): water flow (q), temperature (t); Slag loading speed (v).

**4.3. Modelling the slag cooling equipment [22]**

Picture of screw type slag cooling equipment (picture 4.1a).Modelling (picture 4.1b).

Picture 4.1a. The industrial bottom slag cooling equipment used for experiment




Pciture 4.1b: Modelling the screw type slag cooling equipment

*1.Input parameters:* q- cooling water flow; v- Slag loading speed in the drum;t- Temperature of cooling water; $G_x$- Slag cooling productivity;

*2.Reference parameters:*$T_{xv}$- The temperature of slag to the drum is the constant;

$T_{xv}$ ,$T_{xr}$ – The temperature of slag in and out of the drum, no involvement for survey as an input variable but only measure as reference for marginal limit, not allow to exceed 170$^o$C.

**4.4 Initial experiment**

**4.4.1. Determination of the effect of 3 major technological parameters to the productivity of the slag cooling equipment by experiment**

*a, Some assumptions on the major technological parameters used for experiment*

- The speed of the slag sliding over the screw surface of cooling process is the *even speed* (v);
- The slag surface in the silo is deemed to be *flat*;
- The temperature of the slag from the bottom of the boiler to the cooling water is deemed *unchanged*.

Testing condition:

- Input parameters: Speed of slag (v) vg/ph, variable range:[0,8-1,4]; water temperature (t) $^oC$, [29-33]; water flow, $m^3/ph$, [0,25-0,35];
- The output parameter is the productivity ($G_x$) ton/h, suitable when the temperature of the output slag is ≤ 170$^oC$;

*b, Initial experiment:*

Adopting the intial experimental planning method N=$3^3$ = 9 and 3 central tests of 11. No examination of the modification and attached mathematic model. Surveying the 3 independent variables (v), (t) and (q).

Table 4.1.The result of initial testing $3^3$=9 and 3 central tests

| No | Code | q($m^3$/ph) | v(vg/ph) | t($^o$) | $G_{tn}$(Fre/h) | Temperature of output slag $T_{xr}$ ($^oC$) |
|---|---|---|---|---|---|---|
| 1 | 000 | 0,25 | 0,8 | 29 | 4,20 | 154 |
| 2 | 010 | 0,25 | 1,1 | 29 | 5,35 | 165 |
| 3 | 020 | 0,25 | 1,4 | 29 | 5,60 | 178 |
| 4 | 100 | 0,30 | 0,8 | 29 | 4,25 | 155 |
| 5 | 110 | 0,30 | 1,1 | 29 | 5,50 | 164 |
| 6 | 120 | 0,30 | 1,4 | 29 | 5,6 | 178 |
| 7 | 200 | 0,35 | 0,8 | 29 | 4,70 | 156 |
| 8 | 210 | 0,35 | 1,1 | 29 | 5,65 | 164 |
| 9 | 220 | 0,35 | 1,4 | 29 | 6,30 | 176 |
| 10 | | 0,30 | 1,1 | 31 | 5,80 | 167 |
| 11 | | 0,30 | 1,1 | 31 | 5,90 | 167 |
| 12 | | 0,30 | 1,1 | 31 | 5,85 | 166 |

*c,Experiment by using experimental planning to find the objective function*

The result of the initial test showed that the objective function has surrounded the productivity extreme zone: 6 ton/ temperature of output slag ≤ 170°C) to the stage (step 3) is the test using experimental plannng to find the objective function.

The objective function shall select the quadratic polynomial function of the variables with quandratic 3 variables function with 2 types (formula 3.10):

$$G(q,v,t) = a_1 + a_2 q + a_3 v + a_4 t + a_5 qv + a_6 qt + a_7 vt + a_8 q^2 + a_9 v^2 + a_{10} t^2$$

In which: $G_i, q_i, v_i, t_i$ , are the values at each known points in the experiment sheet;$a_1$, $a_2$ , $a_3$ ,...... $a_{10}$ are the variables to look for.

To develop the above set of equations, we got the algebraic equation system with 10 variables which are the numbers with coefficient ($a_1$, $a_2$ , $a_3$ ,...... $a_{10}$) of the regression

$$G = -31,6 + 19,6q - 0,171v + 1,96t + 3,56qv$$
$$- 0,8qt + 0,279vt + 7,41q^2 - 2,83v^2 - 0,0307t^2$$

function. Solving the equation system, we gain the coefficient of the regression function and experimental planning equation:

To check the compatibility of the experimental planning equation and the experiment data, replace the values of (q), (v), (t) corresponding to the testing codes to gain the calculated productivity value from the planning equation in the table 4.2

Table 4.2 experimental result $3^3$=27

| No. | Code | q($m^3$/ph) | v(vg/ph) | t(°) | $G_{tn}$(Fre/h) | $G_{tt}$(Fre/h) | Difference $\varepsilon$ | Temperature of output slag (°C) |
|---|---|---|---|---|---|---|---|---|
| 1 | 000 | 0,25 | 0,8 | 29 | 4,20 | 4,221 | 0,51% | 154 |
| 2 | 010 | 0,25 | 1,1 | 29 | 5,35 | 5,251 | 1,85% | 165 |
| 3 | 020 | 0,25 | 1,4 | 29 | 5,60 | 5,772 | 3,06% | 178 |
| 4 | 100 | 0,30 | 0,8 | 29 | 4,25 | 4,387 | 3,23% | 155 |
| 5 | 110 | 0,30 | 1,1 | 29 | 5,50 | 5,471 | 0,53% | 164 |
| 6 | 120 | 0,30 | 1,4 | 29 | 5,60 | 6,045 | 4,22% | 178 |
| 7 | 200 | 0,35 | 0,8 | 29 | 4,70 | 4,591 | 2,33% | 156 |
| 8 | 210 | 0,35 | 1,1 | 29 | 5,65 | 5,727 | 1,37% | 164 |

Following table 4.2.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 220 | 0,35 | 1,4 | 29 | 6,30 | 6,355 | 0,87% | 176 |
| 10 | 001 | 0,25 | 0,8 | 31 | 4,30 | 4,504 | 4,74% | 156 |
| 11 | 011 | 0,25 | 1,1 | 31 | 5,50 | 5,701 | 3,65% | 165 |
| 12 | 021 | 0,25 | 1,4 | 31 | 6,50 | 6,389 | 1,71% | 178 |
| 13 | 101 | 0,3 | 0,8 | 31 | 4,50 | 4,590 | 2,00% | 156 |
| 14 | 111 | 0,30 | 1,1 | 31 | 5,80 | 5,841 | 0,70% | 167 |
| 15 | 121 | 0,30 | 1,4 | 31 | 6,60 | 6,582 | 0,28% | 178 |
| 16 | 201 | 0,35 | 0,8 | 31 | 4,60 | 4,713 | 2,46% | 157 |
| 17 | 211 | 0,35 | 1,1 | 31 | 5,70 | 6,017 | 5,56% | 166 |
| 18 | 221 | 0,35 | 1,4 | 31 | 7,10 | 6,812 | 3,19% | 180 |
| 19 | 002 | 0,25 | 0,8 | 33 | 4,40 | 4,540 | 0,09% | 158 |
| 20 | 012 | 0,25 | 1,1 | 33 | 5,50 | 5,905 | 3,67% | 175 |
| 21 | 022 | 0,25 | 1,4 | 33 | 6,56 | 6,760 | 1,16% | 179 |
| 22 | 102 | 0,30 | 0,8 | 33 | 4,60 | 4,547 | 2,84% | 160 |
| 23 | 112 | 0,30 | 1,1 | 33 | 5,80 | 5,965 | 3,19% | 170 |
| 24 | 122 | 0,30 | 1,4 | 33 | 6,70 | 6,873 | 2,59% | 179 |
| 25 | 202 | 0,35 | 0,8 | 33 | 4,50 | 4,590 | 2,00% | 160 |
| 26 | 212 | 0,35 | 1,1 | 33 | 6,10 | 6,061 | 0,63% | 173 |
| 27 | 222 | 0,35 | 1,4 | 33 | 6,80 | 7,023 | 3,29% | 181 |

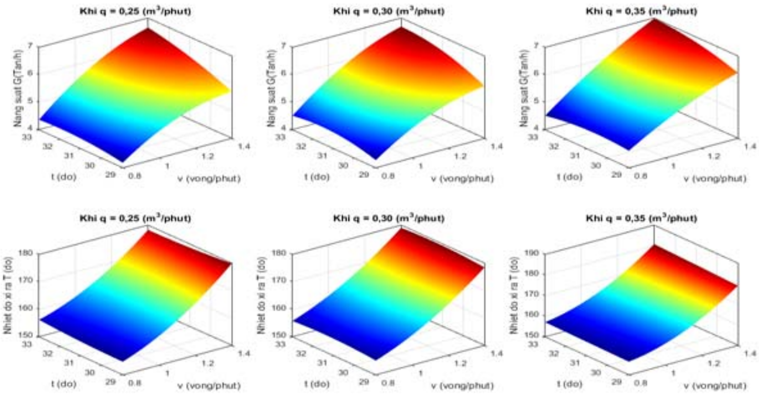
In which: $G_{tn}$ - The experimental productivity; $G_{tt}$ - The consequently calculated productivity;

$\varepsilon$ - The difference between the mathematic and experimental model by percentage %

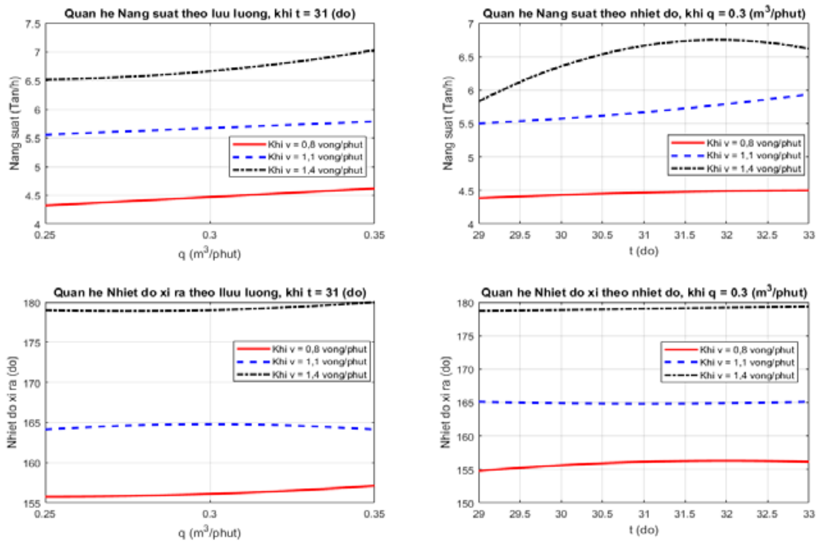
*d, Checking the meaningfulness of the regression function:*Calculation and check the reasonableness of the Student and Fisher coefficient which are meaningful.

### 4.4.2. Developing the experimental graph

Application of MATLAB software to solve the experimental planning equation, modelling and drawing the graph (picture 4.3 and 4.4) (the result of the calculation process in appendix




Picture 4.2: 3D graph of the actual regression function




Picture 4.3: 2D graph showing the relationship between the pairs of technological parameters

### 4.5. Result and scientific debate

- The water flow (q) has the greatest effect and is directly proportional to the productivity ($G_x$), and secondly is the temperature of water (t), and the speed of slag (v) is inversely proportional to the productivity of slag cooling ($G_x$). The explaination for the increase of speed (v) leading to decrease of slag cooling time is that the temperature of output slag ($T_{xr}$) increases, exceeding the applicable temperature of 170$^o$C, on the other hand, the low slag filling coefficient leads to the reduction of productivity;

- The relatively strong direct proportion effect is the combination of water flow and water temperature (qv), the concurrent effect of the combination of slag speed and water temperature (vt) is inconsiderable;

- The result of central test show that the productivity $G_x$= 5,85 ton/h, the extreme approach when the 3 major technological parameters: v=1,1 vg/ph; t= 31$^o$C; q= 0,3m$^3$/p;

**4.6. Applications of the research from the dissertation to the design, manufacture and practical production**

**4.6.1. Screw type slag cooling equipment**

*1, Operational principles (picture 4.1b)*

**4.6.2. Calculation of heat exchange area for screw type cooling equipment**

***1, Calculation of heat emitted from the hot slag:***

Calculation following the technical specifications of the bottom slag cooling equipment for CFB 55MW machine unit with the burning coal quantity of 36.5 ton/h by the following formula [4],[37] :

$$Q = Q_x = G_x.\ C_{px}.\Delta t_x \quad (4.4)$$

Calculation of heat quantity Q for the productivity of 6 ton/h is:

$$Q = G_1 .C_1 (t_1^{'} - t_1^{''})$$

Thus the required heat according to the design productivity of 6 ton/h:

$$Q = \frac{6.1000.0,75.730}{3600} = 912,5 \text{ (kW)} = 912.500\text{W}$$

***2, Calculation of required heat exchange area***

a) The cross section of picture 4.5 of the water flow within the slag cooling screw body:

$$S_{th} = \frac{\pi (d_1^2 - d_2^2)}{4} = \frac{3,14.(0,736^2 - 0,702^2)}{4} = 0,0384 \text{ , m}^2$$

b) The cross section of the water flow in the empty screw:

$$S_{tr} = \frac{\pi .d_{tr}^2}{4} = \frac{3,14.0,296^2}{4} = 0,0688 \text{ , m}^2$$

- Determination of average temperature of the outer surface and hollow shaft:

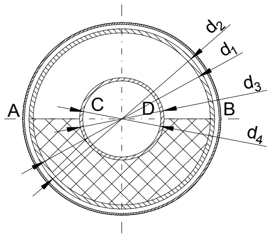
+ The difference of average temperature Δt between water and slag is [4]:

$$\Delta t = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} \tag{4.6}$$

$$\Delta t = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} = \frac{868^o - 100^o}{\ln \frac{868^o}{100^o}} = 355^o C$$

*3, Heat balance equation:*

The quantity of slag in the cooling equipment maximumly equals to ½ of the volume, picture 4.5.




*Picture 4.5: Section of the drum of the slag cooling equipment and slag distribution in pipe*

Including 3 basic forms: *conduction, radiation and convection* with heat balance equation of the equipment by the following formula [4], [6]:

$$Q = Q_x = Q_{bx} + Q_{dn} + Q_{dl} \tag{4.8}$$

In which: $Q_x$ is the heat emitted by the hot slag;$Q_{bx}$ is the heat exchange quantity via radiation;$Q_{dn}$ is the quantity of heat directly conducted from the hot slag to the screw body;

- $Q_{dl}$ is the quantity of heat exchange by convection between the hot slag and air;

***a) Calculation of the quantity of heat exchange via radiation $Q_{bx}$:***

The quantity of heat exchange via radiation is calculated by the following formula [4],[6]:

$$Q_{bx} = q_{bx}.F_{bx} = \varepsilon_{qd}.C_o.\left(\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right).F_{bx} \tag{4.9}$$

**$Q_{bx}$ =1747,84L**

***b) Calculation of quantity of heat exchange via conduction $Q_{dn}$:***

The quantity of heat exchange via conduction from slag to the wall via the surface of the hollow shaft of the screw:$Q_{dn}$= $Q_{dnbody}$+ $Q_{dnaxis}$(4.11)

$$Q_{dl} = \frac{\lambda_{td}}{\delta}.F_{dl}.\Delta t_k = \frac{0,59}{0,335}.0,35.L.64,5 = 39,8.L$$

*4, Calculation of length L of the cooling jacket to achieve the heat exchange area:*

- Heat balance equation (4.8): $Q = Q_x = Q_{bx} + Q_{dn} + Q_{dl}$

Nominal productivity of the equipment is 6 ton/h, determined:

1747,84.L + 294835.L + 39,8.L = 912500→ L = 912500/296622,64 = 3,1 m

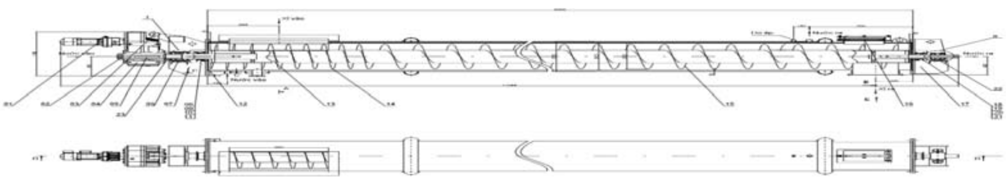
According to overseas experience, select L of about 2,5-3 times of the calculation [32].

Specifically: $L_{tt}$ ≈3 L= 3.3,1= 9,3m, ( **select L=9m**)

### 4.6.3. The structure and working conditions of screw type bottom slag cooling equipment

#### 4.6.3.1 Description of equipment structure

The *general layout* of the slag cooling equipment is shown on picture 4.8.



Picture 4.8. General layout of the CFB screw type bottom slag cooling equipment

4.6.3.2 Working conditions of the equipment:

*a, Working in high temperature:* the screw working at high temperature up to 900°C at the output slag, about 600°C on average in the drum [32], [6]:

b, *The load of major effect to the equipment:*

- *Deformation due to the impact of high temperature:The axial force:* This force produced from the slag transportation, creating the axial force [58]; *Abrasion:* from the friction between the slag and the surface of the screw

*c.4.6.3.3 Some solutions to lengthen the life span of the equipment*

**Some technical solutions:**

- *Material selection:* The materials selected for manufacture of components shall be heat proof, abrasion proof and non-deformation at high temperature [44], [45], [57].:

The outer casing of the equipment shall be made of Q345 steel; the inner casing shall be made of A515 steel (physio-chemical properties and chemical components refer to table 4.5, 4.6 )[57]; The steel axis shall be Mn16 steel. The physio-chemical properties and chemical components refer to table 4.7, 4.8 [57];

+ The screw propeller shall be made of SUS310S heat resistant alloys, (physio-chemical properties and chemical components refer to table 4.9, 4.10), [57].

-*Design solution:* select the axis with transposition (I and II picture 4.8)[56], the screw body is elastic (I, III picture 4.7; the structure of the equipment is proper with firmness [54],[56]:

*Solutions to improve the quality of production, manufacture:*

+ *Welding the machine body:* Fixing and special automatic welding equipment, the welding join shall be resistant to high temperature [51];

*Lathing:* lathing the screw axis on the special fixing set [51], bear the max load of 10 tons, the applicable fixing length is 12 meters. The biggest manufacturing diameter is 1.5 meters, obtaining the coaxial of both tenon-like axis of ≤ 0,05mm and the roughness of tenon-like axis is Rz10.

+ *Polishing:* Special polishing [51], reaching the fine polishing level:

The concurrence of ≤ 0,05mm; the roughness of tenon-like axis is Ra 0,63-1,

+ *Fitting and combining:* The equipment is required to be done by special fitting equipment to ensure the design accuracy.

*4.6.3.4. Calculation and checking the elongation of major components at high temperature:*

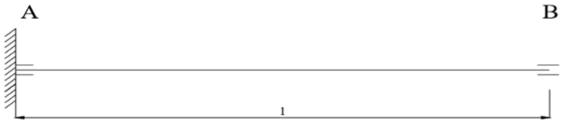
*Some technical specifications for calculation:*

*Determination of the elongation:* The elongation caused by heat to the metal bar of uniform structure can apply the formula in the manual for strength of materials [49]:

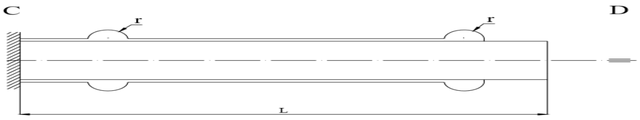
$$\Delta l = \alpha_t l\left(t_2 - t_1\right) \tag{4.18}$$

Calculation of the elongation Δl is inaccurate. Therefore, to have (Δl) it is necessary to determine by actual measuring with value δ= 5,23 mm. This is a significant parameter for the designer of the bearing structure B as per picture 4.8.

With the value δ= 5,23 mm, the relative elongation ε=0,914% is extremely small in comparison to the relative elongation of the material selected for the screw and equipment body.




Picture 4.9. Diagram of screw placed on the block ball bearing A and ball bearing B




Picture 4.10. Diagram of the equipment body placed on the block ball bearing C and ball bearing D

The practice shows that after 15 months of operation with 3 production shifts/day, the equipment operates stably, reaching the productivity and safety (attached with the appendix the confirmation of Na Duong Thermal Power Company).

**4.7. The major technical specifications of the equipment**

- Slag cooling productivity: $G_x$ = 6 ton/h; The max. temperature of input slag: $t_{xv}$ = 900$^o$C; The spinning speed of the transport screw: n =0,8-1,5vg/ph; The max. temperature of output slag: $t_{xr}$ = 170$^o$C; Water flow passing through the equipment: $G_n$ = 0,25-35m$^3$/ph; Temperature of input water: $t_{nv}$ = 29- 33$^o$C; Inner diameter: $d_1$ = 0,67m; Outer diameter: $d_2$ = 0,702m; Outer diameter of screw axis pipe: $d_3$ = 0,32m; Inner diameter of screw axis pipe: $d_4$ = 0,296m.

**4.8. Result of the survey of screw –type slag cooling equipment in practical manufacture**

*1, Continuous running with load for 72 hours of production* by the equipment, adopting the result of the Dissertation.

*2, Major obtained parameters:*The measured parameters are shown on the table (4.3):

Table 4.3. The result of the experiment on the industrial model

| No | Input parameters | | | Measured result | | Average value $y_j$ ton/h | Temperature of output slag ($^o$C) |
|---|---|---|---|---|---|---|---|
| | v vg/ph | t ($^o$C) | q m$^3$/ph | $y_1$ | $y_2$ | | |
| 1 | 1,1 | 31 | 0,30 | 5,9 | 5,8 | 5,85 | 165 |
| 2 | 1,1 | 31 | 0,30 | 5,8 | 5,9 | 5,85 | 164 |

Following table 4.3.

| No | Input parameters | | | Measured result | | Average value $y_j$ ton/h | Temperature of output slag ($^oC$) |
|---|---|---|---|---|---|---|---|
| | v vg/ph | t ($^oC$) | q $m^3/ph$ | $y_1$ | $y_2$ | | |
| 3 | 1,1 | 31 | 0,30 | 6,0 | 5,9 | 5,95 | 164 |
| 4 | 1,1 | 31 | 0,30 | 5,9 | 5,85 | 5,87 | 165 |
| 5 | 1,1 | 31 | 0,30 | 5,8 | 5,85 | 5,87 | 164 |
| 6 | 1,1 | 31 | 0,30 | 5,8 | 5,9 | 5,85 | 164 |
| 7 | 1,1 | 31 | 0,30 | 5,9 | 5,9 | 5,90 | 165 |
| 8 | 1,1 | 31 | 0,30 | 5,8 | 5,85 | 5,825 | 164 |
| 9 | 1,1 | 31 | 0,30 | 5,7 | 5,8 | 5,90 | 158 |
| Average value | | | | | | 5,88 | |

*3, General evaluation of the result verified from the practical production:*

- Technological parameters: Stable flow of cooling water q= 0,30m$^3$/ph, speed v=1,1 vg/ph and the temperature t=31$^o$C; The output parameters: the average productivity obtained 5,88 t/h; Temperature 164- 165 $^o$C; speed v=1,1 vg/ph, water flow q=0,33m$^3$/ph.

*4, Result from continuous running*: from April 2016 to now, the productivity and other parameters are rather stable and equivalent to the newly imported equipment from Finland on operation at the same condition at the factory. The productivity is about 10% in comparison to the old operation *(attached in the appendix 4, the confirmation by Na Duong Thermal Power Company)*

**CONCLUSION OF CHAPTER 4**

From the result of the experiment in chapter 4, it is possible to conclude that:

1. The experimental regression function on the relationship between the productivity of the slag cooling equipment ($G_x$) with the 3 major technological parameters: slag loading speed (v) temperature of cooling water (t) and cooling water flow (q):

$$G = -31,6 + 19,6q - 0,171v + 1,96t + 3,56qv \\ - 0,8qt + 0,279vt + 7,41q^2 - 2,83v^2 - 0,0307t^2$$

2. From the above equation, it is possible to find that the 3 technological parameters that cause impact to the productivity of the cooling equipment ($G_x$)) are as follows: the greatest impact is the flow (q), the second impact is temperature (t) and the speed (v) causes the relevant reduction of temperature of output slag at ≤170°C. The simultaneous impact of the

combination of two factors (qv) leads to the considerable increase of productivity ($G_x$) and the combination of the speed and temperature (vt) is relatively small.

3.The central testing result show that the productivity $G_x$= 5,85 ton/h, has approached the extreme when the three technological parameters are as follows: v=1,1 vg/ph; t= 31°C; q= 0,30m$^3$/ph.

4.Sucessfully applied the designed calculation method for screw-type bottom slag cooling equipment for CFB on the basis of the combination of the *convection, conduction and radiation* processes and application of the 3 major technological parameters (v), (t) and (q) to the operation of equipment to improve the productivity for about 10%, and proved the confidence of the calculation method and the effectiveness of the selected technological parameters by experiment.

## FINAL CONCLUSION OF THE DISSERTATION

1. Based on the theory on the forms of heat exchange and the relation to the type of screw type slag cooling equipment, it is possible to define the slag cooling process which is the heat exchange with the combination of *convection, conduction and radiation* processes. This is a significant basis to set up the calculation model for heat exchange between the cold refrigerant and the hot substance which is the slag.
2. Selected the testing equipments including : the modern industrial bottom slag cooling equipment for CFB of Finland and the modern testing and measurement equipment imported from the countries with advanced industry.
3. Selected the initial experimental method prior to determining the optimization of the major technological parameters impacting the productivity of the slag cooling equipment ($G_x$) including: Flow of cooling water (q), slag loading speed (v) and the temperature of cooling water (t);
4. Studied the experiment and developed the regression function on the relationship between the productivity of the slag cooling equipment ($G_x$) and the 3 major technological parameters: slag loading speed (v), temperature of cooling water (t) and Flow of cooling water (q):

$$G = -31,6 + 19,6q - 0,171v + 1,96t + 3,56qv \\ - 0,8qt + 0,279vt + 7,41q^2 - 2,83v^2 - 0,0307t^2$$

5. From the above equation, it is possible to find that the 3 technological parameters that cause impact to the productivity of the cooling equipment ($G_x$)) are as follows: the greatest impact is the flow (q), the second impact is temperature (t) and the speed (v) causes the relevant reduction of temperature of output slag at ≤170°C. The simultaneous impact of the combination of two factors (qv) leads to the considerable increase of productivity ($G_x$) and the combination of the speed and temperature (vt) is relatively small.

6. The result of the central test shows that the productivity $G_x$= 5,85 ton/h, has approached the extreme point when the three technological parameters v=1,1 vg/ph; t= 31$^o$C; q= 0,30m$^3$/ph;

7. Sucessfully applied the designed calculation, manufacture and bring into production the bottom slag cooling equipment for CFB  for 55MW capacity machine unit on the basis of the heat exchange process: *convection, conduction and radiation* and application of the 3 major technological parameters (v), (t) and (q) to the operation of equipment to improve the confidence of the calculation method and the effectiveness of the selected technological parameters via experiment, gaining the stable productivity with the temperature of the output slag of <170$^o$C and the productivity is 10% higher than that before the application and environmental adaption in accordance with the specified standard of Vietnam.