VANOS
JOURNAL OF MECHANICAL ENGINEERING EDUCATION
http://jurnal.untirta.ac.id/index.php/vanos
ISSN 2528-2611, e-ISSN 2528-2700
Volume 8, Number 2, November 2023, Pages 121-135

The Analysis of Heat Transfer on Hot Air Coffee Roasters at the Appropriate Technology Research Centre, National Research and Innovation Agency in Subang

Azhis Sholeh Buchori[1], Susilawati[2], Nurizzi Rifqi Ferdian[3], Dimas Rizky Umarramdani[4], Dadang Hidayat[5], Oyok Yudiyanto[6], Faadiyah Cheryl Rachelia[7]

[1,2,3,4,7]Department of Maintenance and Repair Engineering, Subang State Polytechnic, Indonesia
Brigjen Katamso Street No. 37 (Back of RSUD), Dangdeur, Subang, West Java, Indonesia
[5]Pusat Riset Teknologi Tepat Guna, Badan Riset dan Inovasi Nasional Subang, Indonesia
K.S Tubun No.5, Cigadung, Kec. Subang, Kabupaten Subang, West Java, Indonesia
[6]Metal Casting Engineering, Politeknik Manufaktur Bandung, Indonesia
Kanayakan Street No. 21, Dago, Coblong District, Bandung, West Java, Indonesia

Corresponding author: usie@polsub.ac.id

Received: 18 July 2023. Accepted: 01 October 2023. Published: 28 November 2023

ABSTRACT

Roasting occurs due to heat transfer from the heating surface into the material. Coffee roasting plays an important role in determining the chemical composition, aroma, and taste of coffee. There are two main types of coffee roasters, namely drum and hot air roasters. This research aims to determine the heat transfer in hot air coffee roasters. The data collected consists of roasting time, coffee bean temperature, roasting room temperature, fuel consumption and air flow speed in the cyclone system chimney and sample was carried out at medium roasting level, with three repetitions. The method used is theoretical analysis and experimental testing. The results showed that the heat transfer mechanism in hot air roasting is a conduction and convection mechanism. The amount of conduction and convection heat transfer in the coffee roasting equipment was carried out in three repetitions. It was also found that factors that influence the rate of heat transfer in hot air roasting equipment are due to conduction and convection, as well as influenced by heat transfer surface area, thermal conductivity, air flow speed from blower pressure and pressure on the gas fuel. The results of the research show that the heat transfer mechanism in hot air roasting is a conduction and convection mechanism. The amount of heat transfer in one repetition of the conduction quantity (Q) is 9222.8 W and the convection rate (Q) is 3209.4 W with an average efficiency of 34.7%, in two repetitions the conduction quantity (Q) is 9883.3 W and the convection rate (Q) is 3444.6 W with the average efficiency is 34.8%, at three repetitions the conduction (Q) is 9690.3 W and the convection rate (Q) is 1123.3 W, the average efficiency is 11.6%. Factors that influence the rate of heat transfer in hot air roasting tools are conduction and convection, heat transfer surface area, thermal conductivity, air flow speed due to blower pressure and pressure on LPG gas fuel.

Keywords: Hot Air, Coffee Roaster, Heat Transfer

INTRODUCTION

Coffee has become a popular drink all over the world. Many people enjoy the taste and aroma of coffee. Coffee processing to produce coffee rice can be classified into three types of processing, namely: dry processing, semi-wet processing and wet processing. one of them is dry processing by roasting coffee. One of the important aspects in coffee production is the roasting process that affects the taste, aroma and final quality of coffee beans [1]. Drying coffee that has been picked and sorted should be dried immediately so as not to undergo chemical processes that can degrade the quality. Drying can be natural and drying artificially [2]. Roasting is a crucial stage in the coffee processing, that is aimed to change markedly the chemical, physical, structural and sensorial properties of the green beans by heat induced reactions. In this way roasting process makes coffee beans suitable for brewing. The green beans are, in fact, characterized by only a weak and greenly aroma and a hard texture hinders their use as food [3]. The beans change color to a dark brown. Initially the process is exothermic [4]. The process of forming the aroma and flavor of coffee can not appear just by drying, but done using high temperatures. Aroma and flavor can be raised using the method of roasting or roasting. Roasting is the core of coffee bean production until it becomes powder, roasting is done using a tool called a roaster [5].

Roasting is a complex process involving the transfer of energy (from the roaster to the beans) and mass (moisture and volatile compounds from the beans to the environment) implicit in the main changes in coffee beans in terms of weight, density, moisture, color and flavor [6]. The best coffee quality can be obtained based on the roasting temperature, roasting time, water content, caffeine, and chlorogenic acid. Existing research only indicates coffee quality based on roasting time [7].

Coffee roasting is a drying process to reduce the water content of coffee beans, usually indicated by weight loss at the end of the process. The roasting process is carried out using a specific temperature until the bean develops, giving the product a distinctive aroma [8]. Classification of roasting by degree of color it is divided into three: light, medium and dark [9]. The roasting process involves applying heat to the coffee beans to produce the chemical and physical transformations necessary to develop the desired flavor characteristics. In addition, roasting induces major physical changes within the coffee beans and determines their behavior in storage, grinding, and brewing. In the present dissertation, the impact of the roasting parameters roasting time, roasting temperature, moisture content, quenching method, and roaster design, on aroma formation, aroma stability, and grinding properties of roasted coffee were investigated [10]. After coffee beans dried to a moisture content of 12.5%, the next process is the processing process for become ground coffee [11]. Bean's temperature and weight loss have been measured on-line by robust sensors. The experimental results allowed better understanding of the phenomena that appears during roasting [12].

Roasting is one of the important processes of coffee production, which significantly affects the quality of roasted coffee. There are many approaches to grilling, applying a rotating cylinder (the standard method of the grilling process), a fixed bowl, and a fluidized bed method [8].

In the coffee industry, roasting is a very important fight against coffee brewing. Some factors that need to be considered during roasting, including roasting machine, roasting time and temperature [13]. Coffee roasting equipment is used to heat coffee beans to the right temperature with optimal timing. In a coffee roaster, heat transfer affects roasting efficiency and results. Therefore, the analysis of heat transfer in coffee roasting equipment is very important to understand in order to improve the roasting process. The results of research on heat transfer in coffee dryers show that modification of the design of the dryer can improve the efficiency of heat transfer and produce better quality coffee beans [14]. Heat is defined as energy transferred by virtue of a temperature difference or gradient. It is a vector quantity, flowing in the direction of decreasing temperature, with a negative temperature gradient. In the science of thermodynamics, the important parameter is the quantity of heat transferred during a process [15].

The heat transfer that occurs during the roasting process takes place. In the study, researchers determining the effect of temperature on mechanical Coffee Roasters, because it is suspected that the effect of temperature on yield, processing capacity and water content in coffee [16]. There are three main heat transfer means in a conventional coffee roaster, conduction, convection and radiation [17].

Heat transfer analysis in coffee roasters by measuring the temperature at various points on the roaster and analyzing the heat distribution during the roasting process. The study found that the right temperature profile and good temperature regulation are essential in producing coffee beans that are roasted evenly and with the desired quality [18].

Heat transfer in the process of heating coffee beans before roasting process by using mathematical models to predict the temperature profile and heat distribution during the heating process. Their results show that proper temperature settings and optimal heating times can produce coffee beans that are ready for the roasting process with good heat transfer efficiency.

From the results of previous studies, it was found that several methods and techniques have been used to analyze heat transfer, including temperature measurement, numerical analysis, and mathematical modeling that provide insight into the influence of factors such as temperature, air velocity, tools, design, and materials used in heat transfer in roasting equipment. The current research is to perform heat transfer analysis on hot air coffee roasters.

RESEARCH METHOD

In this type of research, the theoretical calculation analysis research is used, the results of theoretical calculations are used as parameters during testing. The test was carried out three times and the test results of the heat transfer performance on the hot air. Theoretical calculations require several data parameters, including the actual number of heating pipes in the furnace, pipe length, pipe diameter, blower air speed, burner gas temperature and roasting temperature to be achieved.

The research on heat transfer analysis on hot air coffee roasters was carried out from December 2022 to June 2023 at the research center of Subang National Research and Innovation Agency. In carrying out this research requires the following tools and materials.

Table 1. Tools and materials

Tools and Materials	Specifications	Quantity
Hot air roaster		1
Air flow Anemometer	Benetech GM8902	1
Digital scales	Gram Unit	1
Thermocouple	Type – K Npt 0 -750°C 750°C	1
Green Been	Robusta	3Kg
LPG Gas	3Kg	1

This current research went through several stages of completion starting from observation, tools testing, and analyzing the heat transfer.

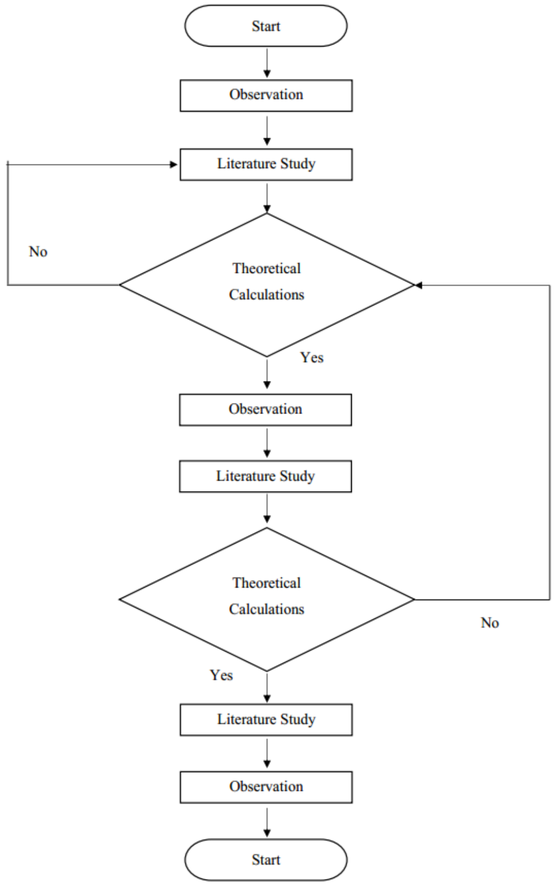

Figure 1. Flow Diagram of research completion

The first stage is initial preparation, which includes conditioning the tools and materials that will be used in this research, including.

1. Conditioning the hot air roasters
2. Conditioning the air flow anemometer, thermocouple, and digital scales

3. Conditioning the green bean and 3 kg LPG gas

After the equipment has been conditioned and is ready, then the green beans are weighed to ensure that the green beans that will be roasted are 1 kg in each trial as well as the weight of 3kg gas to find out the initial weight of the gas that will be used during the test. The installation of gas cylinder regulator to prepare the gas supply to the burner and the position of the gas on a digital scale to determine gas consumption during the roasting process. Next, starting the operation of the hot air roasters to determine the initial temperature in the hot air roaster room and record the initial temperature.

In this step, the blower and ignition burner components have not been turned on. It is also important to make sure the hot air roaster is ready as well as other tools and materials.

The next stage of testing is carried out based on the results of theoretical calculations, the test is carried out three times with different treatments. This aims to determine the conduction and convection heat transfer as well as the average efficiency of heat transfer in the hot air roasting tool which is generated from the actual data during the test whether it is in accordance with the results of heat transfer coefficient and the average efficiency in theoretical calculations.

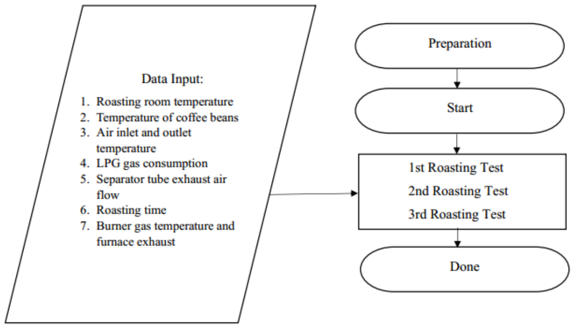

Figure 2. Flow diagram of research procedure

After obtaining the actual data taken during the testing, the next stage is to carry out the analysis stage of heat transfer calculations that occur in the hot air roaster in the three treatments.

To find out the amount of heat transfer in the hot air roaster, it is necessary to carry out calculations in terms of conduction and convection. At this stage, the conduction and convection heat transfer coefficients will be calculated to determine the amount of heat transfer generated in the heating furnace which is transferred to the coffee roasting room.

To obtain the value of the conduction heat transfer coefficient that occurs in the heating pipe, the hot air coffee roaster uses the following steps.

1. Data collection
2. Determining the Number of Heating Pipes
3. Calculating the area of the outer pipe

After obtaining the results of the amount of heat transfer in the heating furnace based on the inside and outside of the heating pipe as well as the average efficiency of the three tests and the results of the quality of hot air coffee roasting, then analyzing the factors that influence the rate of heat transfer in the hot air roaster.

The paired t-test in this research was used to determine the effect of different temperature treatments on the gas burner on the rate of heat transfer that occurs in the hot air roaster.

RESULT AND DISCUSSION

Roasting is a thermodynamic process involving the application of a certain amount of heat energy to food ingredients which causes the absorption of heat from the roasting environment into the coffee beans.

The purpose of roasting is to bring out the flavor of the chemical components dissolved in the coffee which form the flavor of the coffee when it is brewed [19]. This process is carried out as an effort to form the sensory character of coffee. The greater the temperature used when roasting, the less time required for roasting [20].

Based on the research conducted, it is stated that roasting at a temperature of 200°C for 10 minutes can produce well-roasted coffee beans [21].

According to research [19], the roasting stage can cause several changes in coffee beans, including the following.

1. The color changes from green to yellow, (light brown), brown then black.
2. Increase the size of the coffee beans to twice the original size.
3. Density reduction in coffee beans to half the initial density.
4. A loud explosion (pop) occurs in the coffee beans resulting from the release of pressurized gas and water vapor.

The essential things in the formation of sensory character during roasting are the transfer of energy (heat), the presence of water, and a reduction in the density of coffee, so that it can be explained about the stages that occur during the roasting process [22]

Three important stages in the roasting process, namely drying, flavor and color development, and cooling [22].

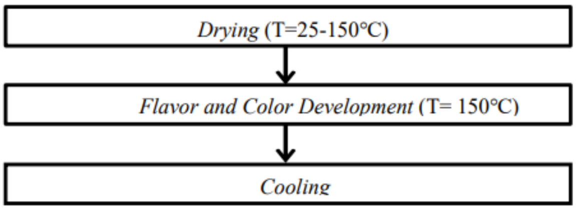

Figure 3. Flow diagram of roasting stages (Source: [22])

The stages of the roasting process that occur can be seen from the time needed to reach the roasting stage as shown in the table.

Table 2. Time required to reach the cracking stage on the roasting drum (Source: [23])

Roasting Temperature (°)	**Time (Minutes)**					
	First crack starts to happen	First crack complete	48 seconds after First crack	Second crack Starts to happen	Second Crack complete	48 seconds after Second crack

210°C	3.8	5.3	6.1	16.9	19.1	20.7
220°C	2.7	5.6	4.4	8.8	11.2	12
230°C	2.4	3.3	4.1	4.9	5.9	6.7
240°C	1.4	2.6	3.4	3.6	3.9	4.7

Figure 4. Coffee bean roasting levels (Source: [20])

The hot air coffee roaster is a coffee roasting tool that uses a convection heat transfer mechanism using hot air flow in a pipe for the roasting process of coffee beans. In its process, air is produced from pressure on the blower, the aim of which is to provide air pressure in the pipe so that air can flow into the coffee bean roasting room. To produce hot air in the pipe, there is a heating medium, namely a burner at the bottom along the heating pipe in the heating furnace. The presence of a combustion burner in the heating stove pipe burns along the heating pipe so that the air in the pipe also heats up and this hot air will later be used for the roasting process of the coffee beans. Heat transfer occurs when heat energy moves from one object to another object that has a lower temperature [24].

Heat transfer is the science of energy transfer in the form of heat which occurs due to temperature differences between objects or materials [25]. In the energy transfer process, there is a speed of heat transfer that occurs, or it is known as the heat transfer rate. Heat transfer can be defined as a process of moving energy from one area to another due to differences in temperature in that area. There are three main mechanisms in heat transfer: conduction, convection, and radiation.

Conduction heat transfer is a heat transfer mechanism that occurs through direct contact between particles in an object or between two objects that are in contact with each other. In a coffee roaster, conduction can occur when the raw coffee beans in the tool come into contact with the hot surface of the tool. The heat will then travel through the coffee beans gradually, changing the temperature of the beans and causing the roasting process.

The heat transfer that occurs in a radial cylinder system, such as in the construction of a heat exchanger in a hot air roaster, can be assumed by solving the following figure and equation.

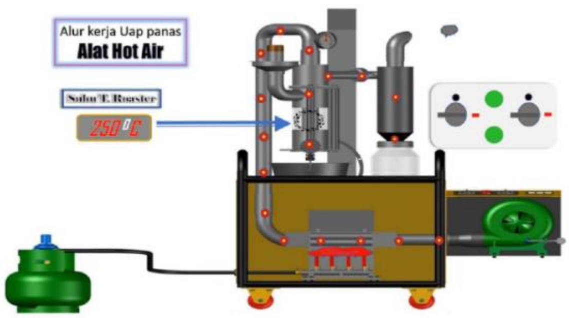

Figure 5. Scheme of the workflow of hot air coffee roasting

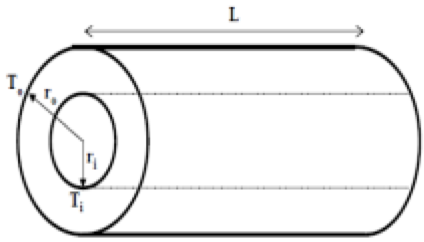

Figure 6. 1-Dimensional heat flow in a hollow cylindrical racial system
(Source: [26])

The equation of Fourier's law becomes:

$Q = -K \frac{dT}{dr} 2\pi rL$..(2.4)

(Source: [27])

Calculating the overall area on a cylinder

$Ai = 2\pi riL$..(2.5.a)

$Ao = 2\pi rol$..(2.5.b)

(Source: [26])

If D is the diameter of the cylinder, then it becomes.

$\frac{ro}{ri} = \frac{Do}{Do}$..(2.6)

(Source: [26])

$\frac{T}{T} = \frac{Ti}{To}$..(2.7)

(Source: [26])

With boundary conditions above the equation of heat flow in the cylinder above equation is used as follows.

$Q = \frac{2\pi rL\ (Ti-To)}{in\ (\frac{Do}{Di})}$..(2.7)

With the formulation of thermal resistance as follows.

$Rth = \frac{in\ (\frac{Do}{Di})}{2\pi kl}$..(2.8)

The factors that influence the rate of conduction heat transfer are:

1. The temperature difference between the two surfaces (ΔT). The greater the temperature difference, the faster the heat transfer
2. The distance between the two surfaces / thickness / length (l), the thicker it is, the slower the heat transfers.
3. Surface area (A), the greater the surface area, the faster the heat transfer.

Convection is heating transfer that occurs through the movement of fluid or air that carries heat energy. In the context of a coffee roaster, convection occurs when hot air moves through the roaster and flows around the coffee beans. Hot air carries heat energy which then transfers heat to the coffee beans. Good air movement in the roaster is very important to ensure efficient and even heat transfer to all parts of the coffee bean. Judging from its working principle, the hot air roaster uses a blower to provide pressurized air to flow air into the roasting room, so the convection heat transfer in the hot air roaster is a type of forced convection.

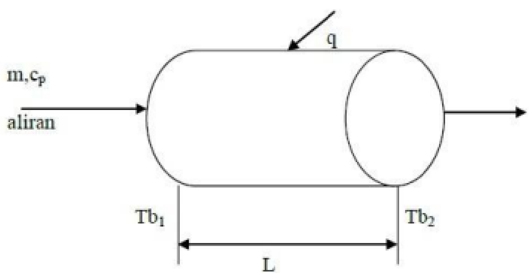

Figure 7. Convection Heat Transfer Process in Cylinders
(Source:[28])

The process of heating and cooling a fluid flowing in a closed channel is an example of a heat transfer process. The heat transfer rate at a certain temperature difference can be calculated using the equation.

$$q = -hA(Tw - T\infty)$$

(Source: [29])

Or use the equation for the rate of convection heat transfer in a hollow cylinder using the following equation.

$$\frac{Q}{t} = h.A.\Delta T$$

(Source: [26])

Noted:

Q = heat transfer rate (kj, det, Watt)

h = convection heat transfer coefficient (W / $m2$, °C)

A = Heat transfer surface area ($fft2, m2$)

Tw = Cold temperature (°C, K)

$T\infty$ = Surrounding temperature (°C, K)

ΔT= Temperature difference (wall temperature Tw – fluid temperature T∞), °C

The minus sign (-) is used to fulfil the Second Law of thermodynamics, while the heat transferred always has a positive sign (+).

The factors that influence the rate of convection heat transfer are:

1. The surface area of the object (A), the greater the surface area of the object in contact with a fluid, the faster the heat transfer.
2. Difference in object temperature (ΔT), the greater the temperature difference between the object and the fluid surface, the faster the rate of convection heat transfer.
3. Convection coefficient (h), depends on the shape of the surface and is obtained experimentally. For example (h) in the human body is obtained (h) with a value of 7,1 $Js^{-1} m^{-2} K^{-1}$.

The heat transfer due to fluid outside the pipe is analyzed based on conduction heat transfer that touches the heating pipe arrangement. The magnitude of the heat transfer coefficient by convection in the pipe is greatly influenced by the temperature of the burner gas that touches the pipe in the row of heating pipes in the heating furnace. You need to know the arrangement of the pipes in the hot air roasting furnace heating furnace first. The type of fluid flow found in hot air roasting tools is the staggered type. To find out the number and surface area of the hot air roasting furnace, use the following equation.

$N = N1 + N2$

(Source: [28])

Note:

N = Number of heating pipes

$N1$ = Number of pipes in row 1

$N2$ = Number of pipes in the 2nd row

After knowing the amount of N in the heating pipe, then calculating the surface area of the hot air roasting tool heating pipe using the following equation.

$A = N\pi D$L

(Source: [28])

Note:

A = Surface area (m)

N = Number of Pipes

D = inner diameter of heating pipe (m)

L = Length of heating pipe (m)

The heat transfers due to fluid flow that occurs in the pipe is an internal flow where the boundary layer does not allow it to develop because it is limited by the surface. The heat transfer that occurs in the pipe is a type of forced convection due to blower pressure. To calculate the value of the heat transfer coefficient by convection in the pipe on a hot air roasting device, it is necessary to pay attention to the amount of conduction heat transfer obtained from the heating furnace to heat the air in the pipe and the number of arrangements contained in the heating pipe.

After finding the surface area of the inner heating pipe, then find the air flow velocity in the pipe ($Vmax$) with the following equation.

With the provision of:

$$(ST - D) < 2 > (SD - D)$$

With Formulation

$$Vmax = \frac{ST}{SD - D} \times V$$

(Source:[28])

After knowing the speed of the air flow and the wall surface area of the inner pipe, the next step is to know the rate of convection heat transfer from the heating furnace to the roaster room along the flow pipe of the hot air roasting tool. You need to know the value of the Reynolds number (ReD) and the Nusell number (NuD). With the following stages and equations.

Determining ($Tmean$) the average temperature of the air from the heating pipe and roaster chamber, with the equation.

$$Tmean = \frac{Tci + Tco}{2}$$

Note:

$Tmean$ = Average temperature

Tci = Inlet air temperature from the furnace (°C)

Tco = Air temperature leaving the roasting room (°C)

After obtaining the average temperature, the next step is to look for the properties of the air at a certain temperature. After finding the property data, then look for the value of the Reynolds number (ReD) to determine the type of flow using the equation.

$$ReD = \frac{P \times V \times D}{\mu}$$

(Source: [28])

Note:

P = Density of air (kg/m3)

V = Maximum flow velocity of flue gas (m/s)

D = Inner pipe diameter (m)

μ = Dynamic viscosity (kg/ms)

In the internal Reynold number flow, there are 2 types of flow, namely:

1. Laminar Flow

This flow occurs if the value of ReD < 2300. Heat transfer in this flow can be seen from the constant surface heat flux and constant surface temperature.

2. Turbulent Flow

This flow occurs if the ReD value is ≥ 2300. In this flow, the Nusselt number can be calculated using the Dittus-Boelter equation. With the influence of the type of heat transfer become one of the factors taken into account (cooling or heating).

The overall heat transfer coefficient is the overall thermal resistance between two fluids (cold fluid to hot fluid) through which heat transfer occurs, including the presence of fouling factors that may occur after the heat exchanger is used. The overall heat transfer coefficient can be calculated by adding up the thermal resistance due to conduction and convection between two fluids bounded by the cylinder wall. The general equation for calculating the overall heat transfer coefficient is:

$$Rtot = \frac{1}{U \times A}$$

(Source: [28])

Note:

$Rtot$ = Total resistance

U = Overall heat transfer coefficient (W/m.k)

A = Total area of the heat transfer surface (m2)

Thermal resistance involves flow convection resistance inside the cylinder, conduction resistance in the cylinder material and flow convection resistance outside the cylinder, so the following equation can be taken.

$$Rtot = \frac{1}{ho2.ro.L} + \frac{in(\frac{ro}{ri})}{2KL} + \frac{1}{hi2rio}$$

(Source: [28])

Note:

$Rtot$ = Total resistance

ho = Convection heat transfer coefficient outside the pipe (W/m2 k)

hi = Convection heat transfer coefficient in the pipe (W/m2 k)

ro = Inner radius of the pipe (m)

ri = Outside radius of the pipe (m)

L = Pipe Length (m)

K = Thermal conductivity (W/m2 k)

$$U = \frac{1}{\frac{1}{ho} + \frac{ro}{k} + \frac{ri}{ro} + \frac{1}{in(hi)}}$$

(Source: [28])

Note:

U = Overall heat transfer coefficient (W/m k)

ho = Convection heat transfer coefficient outside the pipe (W/m 2 k)

hi = Convection heat transfer coefficient in the pipe (W/m 2k)

$r\ o$ = Inner radius of the pipe (m)

$r\ i$ = Outside radius of the pipe (m)

K = Thermal conductivity (W/m 2 k)

From the results of testing the hot air roaster three times, material parameters were found for data processing. The time and temperature used are based on the coffee roasting test. The data obtained is as follows:

Table 3. Test parameter results data

Parameter	Testing			Unit
	1	2	3	
Time	**14**	**26**	**24**	**minut**
LPG fuel weight before	8.2	7.2	6.3	kg
Blower Rotation Speed	16.000	16.000	16.000	rpm
Blower Air Flow Speed	26.2	24.8	24.2	m/s
Coffee Bean Separator Pipe Exhaust Speed	3.2	3.3	3.3	m/s
Air velocity at the heating furnace exhaust	4.8	4.0	4.2	m/s
Burner gas temperature	700	748	734	℃

Air temperature from the blower	31	31	31	°C
Roaster Room Temperature	360	305	260	°C
Coffee Bean Temperature	271	210	214	°C

Table 4. Theoretical calculation of heat transfer in hot air roaster

Time (Minutes)	Roasting temperature	Conduction Heat Transfer Coefficient (W)	Roaster Room Convection Heat Transfer Coefficient	Convection Heat Transfer Coefficient in coffee	Average efficiency (%)
7.80	208	2413.1	3677.2	3926.6	61

It was found that the results of theoretical calculations to determine the rate of conduction and convection heat transfer in a coffee roaster showed that the time required to reach 700°C burner temperature was 7.8 minutes. The effect of the burner temperature on increasing the temperature in the heating furnace was 650°C with a conduction heat transfer rate of (Q) 24131.1 W. It was also found that the effect of the temperature on the gas burner on increasing the temperature in the roaster room was 208.9°C with a convection heat transfer rate to the roaster room of (Q) 3677.2 W and it was also found that the convection heat transfer coefficient for coffee beans was (Q) 3926.6 W with an average heat transfer efficiency of 61%.

From the results of the calculation of the overall heat transfer coefficient of the hot air type coffee roaster, it was found that the overall heat transfer rate was high in terms of the heating furnace (conduction) of the hot air roaster to transfer heat to the roaster chamber (convection) from three treatments. After knowing the overall heat transfer coefficient of conduction and convection, the average efficiency will then be calculated to determine the average heat transfer efficiency of the hot air coffee roaster in the three treatments.

Table 5. The results of heat transfer coefficient and average efficiency of the hot air roasters

Testing	Burner Temperature	Temperature In Coffee	Heat Transfer Rate			Efficiency (%)
			1	Pipe Convection	Coffee Convection	
1	700	271	9222.	109	320	34.7
2	748	210	9883.3	7481.3	3444.6	34.8
3	734	214	9690.3	7481.3	1123.3	11.6

From the results of the calculation of the heat transfer rate that occurred in the hot air roaster, which is viewed in terms of conduction and convection, the results of the heat transfer coefficient and average efficiency of the three treatments are known. In the 50th treatment at a burner temperature of 700°C, it was found that the resulting conduction heat transfer rate coefficient was (Q) 9222.8 W and based on convection from along the pipe to the coffee (Q) 3209.4 W with an average heat transfer efficiency of 34.7%. In the second test, the conduction transfer in the furnace was (Q) 9883.3 W and the convection heat transfer to the coffee was (Q) 3444.6 W with an average heat transfer efficiency of 34.8%. In the third test, it was found that the conduction heat transfer in the furnace was (Q) 9690.3 W and the convection heat transfer along the pipe to the coffee was (Q) 1123.3 W with an average heat transfer efficiency of 11.6%. Roasters should operate with a low air-to-bean ratios and a high proportion of conductive heat transfer [30].

CONCLUSION

From the results of the discussion that has been carried out regarding heat transfer analysis research from the hot air coffee roasting furnace heating furnace, several conclusions have been drawn, namely as follows:

1. The results obtained from 3 trials of the hot air coffee roasters in the first testing are gas burner temperature to reach 700°C took 14 minutes. In the second test to reach 748°C, it took 26 minutes and in the third test to reach 734°C, it took 24 minutes. The rate of conduction heat transfer from the gas burner to the pipe in the heating furnace in three tests was found to be (Q) 9222.8 W, (Q) 9883.3 W, (Q) 9690.3 W. It was found that the rate of convection heat transfer from the heating furnace to the roaster chamber in three tests was (Q) 1099.3W, (Q) 7481.3 W, (Q) 7481 W and the convection heat transfer rate to the coffee beans from three tests was (Q) 3209.4 W, (Q) 344.6 W, (Q) 1223.3 W, with an average efficiency of The average conduction and convection heat transfer is 34.7%, 34.8% and 11.6%.
2. From the results, it was concluded that the factors that influence the heat transfer of hot air roasters are conduction and convection in hot air roasters.

REFERENCES

[1] N. Supriana, U. Ahmad, S. Samsudin, and E. H. Purwanto, "Pengaruh Metode Pengolahan dan Suhu Penyangraian terhadap Karakter Fisiko-Kimia Kopi Robusta," *Jurnal Tanaman Industri dan Penyegar*, vol. 7, no. 2, p. 61, Jul. 2020, doi: 10.21082/jtidp.v7n2.2020.p61-72.

[2] P. Lestari, S. Tp, and W. Pertama, "TEKNOLOGI PENGOLAHAN KOPI."

[3] A. Fabbri, C. Cevoli, L. Alessandrini, and S. Romani, "Numerical modeling of heat and mass transfer during coffee roasting process," *J Food Eng*, vol. 105, no. 2, pp. 264–269, 2011, doi: https://doi.org/10.1016/j.jfoodeng.2011.02.030.

[4] R. A. Buffo and C. Cardelli-Freire, "Coffee flavour: An overview," *Flavour and Fragrance Journal*, vol. 19, no. 2. pp. 99–104, Mar. 2004. doi: 10.1002/ffj.1325.

[5] E. P. Liana, A. Fiatno, and D. Gusman, "Analisis Kinerja Alat Raosting Kopi Kapasitas 2kg Tipe Silinder

Horizontal," *Jurnal Teknik Industri Terintegrasi*, vol. 6, no. 1, pp. 101–107, Apr. 2023, doi: 10.31004/jutin.v6i1.11749.

[6] R. Eggers and A. Pietsch, "Technology I: Roasting," in *Coffee*, R. J. Clarke and O. G. Vitzthum, Eds., Wiley, 2001, pp. 90–107. doi: 10.1002/9780470690499.ch4.

[7] Ainunnisa Fanny and Syamdhiya Rani Husna, "EVALUASI KINERJA ALAT ROASTING KOPI," 2020.

[8] H. Yohanes, W. S. Kompiang, and S. E. Agus, "Study of Heat Transfer and Product Characterization in Spouted Bed Coffee Roaster," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 92, no. 2, pp. 182–190, 2022, doi: 10.37934/arfmts.92.2.182190.

[9] J. A. Vignoli, M. C. Viegas, D. G. Bassoli, and M. de Toledo Benassi, "Roasting process affects differently the bioactive compounds and the antioxidant activity of arabica and robusta coffees," *Food Research International*, vol. 61, pp. 279–285, 2014, doi: https://doi.org/10.1016/j.foodres.2013.06.006.

[10] J. Baggenstoss, "Coffee roasting and quenching technology-Formation and stability of aroma compounds," *Doctoral dissertation, ETH Zurich*, 2008.

[11] A. Hamni, G. A. Ibrahim, and S. Harun, "Implementasi Sistem Gasifikasi untuk Pengeringan Biji Kopi," 2014.

[12] J. A. Hernández, B. Heyd, C. Irles, B. Valdovinos, and G. Trystram, "Analysis of the heat and mass transfer during coffee batch roasting," *J Food Eng*, vol. 78, no. 4, pp. 1141–1148, 2007, doi: https://doi.org/10.1016/j.jfoodeng.2005.12.041.

[13] E. Panggabean, *Buku Pintar Kopi*. Jakarta Selatan : PT AgroMedia Pustaka, 2011.

[14] S. M. Deotale, S. Dutta, J. A. Moses, and C. Anandharamakrishnan, "Stability of Instant Coffee Foam by Nanobubbles Using Spray-Freeze Drying Technique," *Food Bioproc Tech*, vol. 13, no. 11, pp. 1866–1877, 2020, doi: 10.1007/s11947-020-02526-6.

[15] JP Holman, "HEAT AND MASS TRANSFER SECOND EDITION," vol. 2, 2007.

[16] F. D. Kurniawan *et al.*, "ANALISIS LAJU ALIRAN PANAS PADA MESIN SANGRAI KOPI (ROASTING COFFEE) TERHADAP HASIL SANGRAI KOPI."

[17] A. Binmahfuth, "Coffee Processing."

[18] Marcone M, "Book review : Espresso Coffee – The Science of Quality," 2006, Accessed: Nov. 26, 2023. [Online]. Available: https://doi.org/10.1016/j.foodres.2005.07.002

[19] S. Rao, *Everything But Espresso : Professional Coffee Brewing Techniques*. 2014.

[20] D. Pitra, "Rancang Bangun Alat Penyangrai Dan Pendingin Biji Kopi Otomatis Berbasis Mikrokontroler ATMEGA 2560," 2018. [Online]. Available: https://api.semanticscholar.org/CorpusID:126705518

[21] B. Thomas Edvan, R. Edison, dan Made Same, M. Jurusan Budidaya Tanaman Perkebunan dan, and S. Pengajar Jurusan Budidaya, "Pengaruh Suhu dan Lama Penyangraian pada Mutu Kopi Robusta (Coffea robusta)," 2016.

[22] N. T. Fadai, J. R. Melrose, C. P. Please, A. Schulman, and R. A. Van Gorder, "A heat and mass transfer study of coffee bean roasting," *Int J Heat Mass Transf*, vol. 104, pp. 787–799, 2017, [Online]. Available: https://api.semanticscholar.org/CorpusID:126207456

[23] N. Wang, "Physicochemical Changes of Coffee Beans During Roasting," 2012. [Online]. Available: https://api.semanticscholar.org/CorpusID:32592941

[24] I. Supu, B. Usman, S. Basri, and S. Sunarmi, "Pengaruh suhu terhadap perpindahan panas pada material yang berbeda," *Jurnal Dinamika*, vol. 1, no. 7, pp. 62–73, 2016.

[25] J. P. Holman, "Experimental methods for engineers: 6th edition," *Exp Therm Fluid Sci*, vol. 9, 1994, [Online]. Available:

https://api.semanticscholar.org/CorpusID:125584072

[26] L. Hakim, "Analisa Teoritis Laju Aliran Kalor Pada Ketel Uap Pipa Api Mini Industri Tahu Di Tinjau Dari Koefisien Perpindahan Panas Menyeluruh," *SURYA TEKNIKA* , vol. 1, no. 4, 2016.

[27] L. Buchori, "PERPINDAHAN PANAS (HEAT TRANSFER)."

[28] YA Cengel, "Heat and Mass Transfer A Practical Approach, 3rd Edition by Cengel," *Heat and Mass Transfer A Practical Approach*, vol. 3, 2003.

[29] J. P. Holman, *Heat Transfer. 10th Edition*. New York: McGraw-Hill, 2010.

[30] S. Schenker, "INVESTIGATIONS ON THE HOT AIR ROASTING OF COFFEE BEANS," 1968.