FIRST EXPERIMENTAL IRON PROCESS BASED ON THE MONTALAT IRON SITES IN CENTRAL KALIMANTAN, INDONESIA

Proses Eksperimen Peleburan Besi Pertama Berdasarkan Situs Besi Montalat di Kalimantan Tengah, Indonesia

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Abstract. *This article is based on an experimental iron furnace from archaeological sites in Central Kalimantan – Indonesia from July 2019. The iron furnace for the experiment is replicated the original iron furnaces from the latest research were found in year 2017 in the Benangin and Temelalo sites from Central Kalimantan, Indonesia. The experiment aims to prove whether the iron furnace can melt metal. From the archaeological experiment can answer questions about the iron process in Central Kalimantan in the past with the local resource's laterite and hematite. From the results of archaeological experiments of duplicate iron furnaces can make iron raw materials into melts can extract iron from hematite and laterite raw materials. The results shown the ancient people in Central Kalimantan were able to made iron from raw materials and process it as iron ingot.*

Keywords: *Iron Smelting, Laterite Iron, Central Kalimantan*

Abstrak. Artikel ini didasarkan pada percobaan tungku besi dari situs arkeologi di Kalimantan Tengah - Indonesia pada bulan Juli 2019. Tungku besi untuk percobaan ini mereplikasi tungku besi asli dari penelitian logam terbaru yang ditemukan tahun 2017 di situs Benangin dan Temelalo dari Kalimantan Tengah, Indonesia. Eksperimen ini bertujuan untuk membuktikan apakah tungku besi dapat melebur logam. Dari percobaan arkeologi ini dapat menjawab pertanyaan tentang proses peleburan besi di Kalimantan Tengah di masa lalu dengan sumber daya lokal berupa laterit dan hematit. Dari hasil percobaan arkeologi duplikasi tungku besi yang dapat membuat bahan baku besi menjadi lelehan yg mengekstrak besi dari bahan baku hematit dan laterit. Hasil penelitian menunjukkan masyarakat kuno di Kalimantan Tengah telah mampu membuat besi dari bahan baku dan mengolahnya menjadi bahan logam setengah jadi.
Kata kunci: Peleburan Besi, Besi Laterit, Kalimantan Tengah

1. Introduction

In general, experiments are specifically designed to produce the data needed to answer research questions (Margono, 2007, p. 48). The experimental method is an experiment conducted by researchers to determine the effects after receiving a treatment experiment. In archeology, the experiments are controlled and replicate past phenomena, in sequence, to generate and test hypotheses to provide or enhance analogies for archaeological interpretation. It can be "valid" or not, however validity from the result experiment does not mean "true", it follows the principal behind that hypothesis can continue until replaced by better hypothesis (Outram 2008, 1; Busuttil 2013, 60).

In archaeological research, the experimental archeology is not widely practiced, it still plays a marginal role. Meanwhile experimental archeology can used to answer questions to tests hypothesis about a site or artifact, utilize experiments to test the data collection methods used about the past to ensure the data is "true" for representation of the past (Millson, 2011, p. 3). Scientific knowledge from the experimental by understanding progresses and framing these ideas as hypotheses and then testing them to show not that they are right, but that they remain valid, individual experiences can also be used to inform structure experimentation since they are frequently repeated individually while adhering to common principles, leading to the accumulation of knowledge and comprehension over time. (Hurcombe *et al*. 2016, 15).

Several archaeological experiments have been carried out in England, in the Brue Valley, Somerset UK, where experiments on human paths during the Iron Age and canoeing have been carried out (Brunning 2016, 37). Another experiment was carried out in Southern Italy to carry out reconstruction experiments on Bronze Age buildings based on ethnographic data (Caruso and Speciale 2016, 49). In Indonesia, experimental archeology has not been carried out widely by archaeological researchers and communities, archaeology in Indonesia slowly changed from a cultural-historic approach to a natural-historic approach (Kaharudin, 2019, p. 29). Some experimental archaeological research on stone tools was carried out by Ali Akbar and Ansar Rasyid (Akbar 2016, 17–26; Rasyid 2017, 127–144).

In 2017 and 2018, the research team from The National Research Center of Archaeology and the Regional Agency for Archaeological

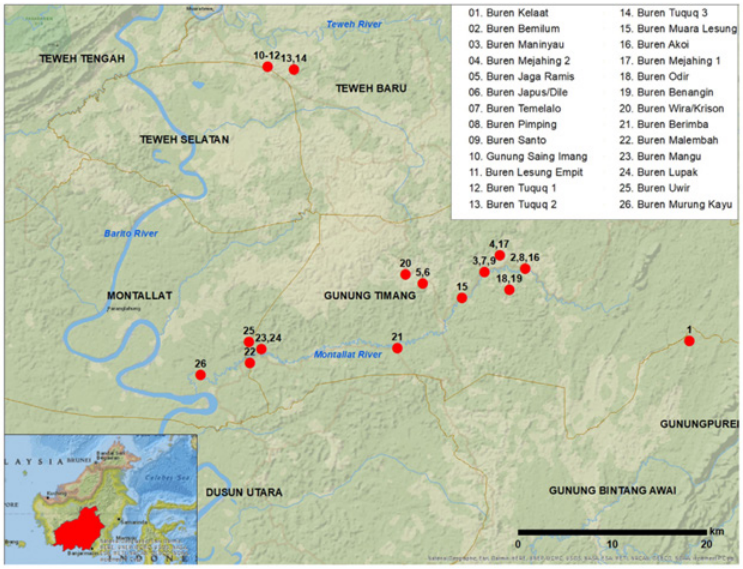


Figure 1. Map of the location archaeological iron smelting sites in Central Kalimantan (Source: Hartatik *et al*., 2023, p. 2)

Research in South Kalimantan Province (now National Research and Innovation Agency) conducted research in the upper Barito River, in the Teweh River and the Montalat River, which is a tributary of the Barito River. From the 2017 and 2018 research it is known that there are 11 locations that are the source of the materials and the places for smelting iron (see Hartatik *et al*. 2017, 60; Hartatik *et al*. 2018, 84). In 2021 totaled 26 iron smelting sites were found (Hartatik *et al*., 2023, p. 1).

Using the dating from C14 taken from the charcoal materials from the sites and analyzed in laboratory Waikato University, New Zealand. The dating results from Buren Jaga is 153 ±17 BP (1780 – 1814 AD) (Wk-50270, 2019), Buren Mejahing results is 198 ±14 BP (1738 – 1766 AD) (Wk-50271, 2019), Buren Temelalo results is 295±15 BP (1640 – 1670 AD) (Wk-50272, 2019) and Buren Benangin results is 229 ±15 BP (1706 – 1736 AD) (Wk-50273, 2019). The results from different sites shown from the smelting sites are from 17th century to 19th century (Hartatik *et al*. 2019, 145–148). This period retrieved the smelting iron activity in this area very intensive, the other iron smelting site in Kalimantan were found in Cililin Cave Site 1 in Kelumpang Hulu sub district, Kotabaru District, South Kalimantan from C14 taken from charcoal materials result is 1980–1880 calBP and 1820–1720 calBP (Hartatik *et al*., 2023, p. 2).

The original furnaces from the Temelalo and Benangin sites are still in good condition. For the Buren Benangin site itself, excavation began in 2017 and continued into 2018, from this research, we understand if the raw materials from the smelting activity not import from others place but locally taken from surrounding area. The fuel also not from the coal but from charcoal, although the coal deposite expose and laydown not far from the site, looks the knowledge how to processing the coal from the Dutch (Hartatik *et al*. 2018, 130–148). Buren Temelalo site was excavated in 2018, this furnace has same characteristic with Benangin furnace, have two furnace which is adjacent, this is to remelting iron after the first process to make iron purer. The blocks on the inside of furnaces are square and on the outside are rounded, it is a type of iron furnace from Kalimantan. Buren Benangin is a model and the reference for experiment iron we will discuss in this article due to its condition (Hartatik *et al*. 2018, 136–150).

2. Method

In this experiment, various instruments were used to measure heating and the materials used. The experiment was recorded in a notebook and documented with photos. To carry out this experiment, several steps were required which will explain more in the result and discussion. For safety reasons, the place for the experiment chosen needed to be a safe place and located a distance from residents, to avoid the spread of fire. To conduct an experiment, several steps are required.

1. Preparing the experimental site, the place

Figure 2. Furnace Buren Benangin site (left) and furnace Buren Temelalo site (right)
(Left source: Author, 2019, right Source: Agisoft photoscan software, 2019)

chosen must be a safe place and located some distance from housing or residents, because for safety factors, the experimental site was also chosen not too shady to avoid the spread of fire to the surrounding trees.

2. To replace the function of the double piston bellows, an electric blower with a capacity of 2 inches and 3.000 RPM (rotation per minutes) was used and the air pipe used an iron pipe with a size of 2 inches. This is done because of the efficiency factor alone.
3. To lift the iron from the furnace, large pliers are needed.
4. To make and shape the stove, square wooden blocks are needed to replace the fossilised stones found in Buren Temelalo (see Hartatik *et al*. 2018 report).
5. Water and barrel are needed for safety factor in case of unwanted things, it also serves as a softener for the clay so that it is not hard.
6. Thermometer with the ability to measure up to 1763° Celsius, setting in S type.
7. Iron metal detector and magnet to distinguish iron or non-iron.
8. Charcoal made from *Halaban* wood for the fuel.
9. Limestone as flux, from the local area in Kandui Regency.
10. Iron ore in the form of laterite and hematite taken from local area.
11. Clay for making furnaces taken from the local riverbank to make replica of furnace.

3. Result and Discussion

Experimental activities were carried out from 19 July to 21 July 2019, from morning to night, with sunny weather conditions and temperatures between 25° C - 27° C, all of the clays, charcoal, laterite, hematite and heat were measured and written in the notebook, every step of the experiment also documented with photos, the location take place in the in the villagers' fields. This ancient iron metal smelting furnace experiment process was carried out for the first time in Indonesia so there are no specific guidelines for carrying it out, however iron smelting furnace experiments have been carried out in various countries such as in Cambodia by Leroy *et al*. in 2020 at the Angkor period iron metal smelting site (13- 14 Century) which was successful demonstrated that the production of slag and iron was not in line with the archaeological systems surrounding Phnom Dek and that there were deficiencies in the process and challenge with the experiments materials (Leroy *et al*. 2020; 15). Experiment of bowl furnace from England taken by Marks *et al*. which focuses on the shape of the furnace which is effective for carrying out the melting process because its shape makes the burning process more focused and makes it more fuel efficient and speeds up the melting process (Marks *et al*. 2020; 11).

From the two experimental examples mentioned, experimental research really helps archaeologists to understand the processes that occurred in the past, especially in the iron smelting process, so that they will gain a better understanding of the process of making artifacts in the past, especially the iron smelting process that was carried out. By understanding the processes that occur, it is hoped that more complete knowledge will be gained about the region's past and its impact on other regions and its impact on understanding the historical development of technology.

In this first experiment, four models of iron melting furnaces were made (furnaces A, B, C, and D) which were duplicates of the melting furnaces found in Benangin and Temelalo. This iron melting furnace was also modified to see the results obtained if the modification was carried out. Modifications are made following the parameters created which are then recorded quantitatively.

3.1 Furnace A

Furnace A was constructed in the same shape of Buren Benangin furnace form. We

Figure 3. Experiment process furnace A
(Source: Author, 2019)

use blocks to make furnace shape based on the block artifacts discoveries near the Temelalo sites see (Hartatik *et al*., 2018). For furnace, yellow clay was used from the local riverbank near the sites. This furnace has two tuyeres that were formed from bamboo and then the bamboo form removed, this furnace did not require the use of flux. The smelting process took four hours 35 minutes. Magnet could interact with the ingot.

3.2 Furnace B

Furnace B also follows the shape of the Buren Benangin furnace form and were made of gray clay, the primary characteristic of this clay is that it is softer than yellow clay and quite difficult to form. This furnace has two tuyeres, one of the tuyeres was left with bamboo remaining inside the furnace meanwhile the other had the bamboo removed. No flux was used for this furnace, the duration experiment process needed four hours 35 minutes. During the process, the tuyere with bamboo remaining was destroyed by fire. Magnet could interact with the ingot.

3.3 Furnace C

Furnace C cone shape was formed from yellow clay, this furnace has two tuyeres, both tuyeres fired with the bamboo left inside the furnace. Flux was ased for this furnace, placed on the ground of the furnace, the duration of experiment process was nine hours 30 minutes. During the process, both tuyeres with the bamboo was destroyed by the fire. Magnet could interact with the ingot.

Figure 4. Experiment process furnace B
(Source: Author, 2019)

Figure 5. Experiment process furnace C
(Source: Author, 2019)

Figure 6. Experiment process furnace D
(Source: Author, 2019)

3.4 Furnace D

Furnace D used a rounded shape form made of yellow clay. This furnace has two tuyeres, both tuyeres with the bamboo supports left inside furnace. Flux was added to the furnace on the ground of furnace, the duration experiment process required nine hours 30 minutes. During the process, both tuyeres with bamboo intact apart from the furnace were destroyed by fire. Magnet could interact with the ingot. A comparison table of the dimensions for the existing comparison furnace can be noted, the comparison table can be seen in table 1 below.

Table 1. Furnace Dimensions Comparison

No.	Description	Furnace A	Furnace B	Furnace C	Furnace D
1	Outer Height	51 cm	48 cm	53 cm	50 cm
2	Inner Height	51 cm	41 cm	50 cm	43 cm
3	Bottom Outer Diameter Ɵ	82 x 65 cm	70 x 70 cm	77 x 73 cm	80 x 80 cm
4	Upper Outer Diameter Ɵ	47 x 37 cm	32 x 34 cm	29 x 30 cm	30 x 30 cm
5	Thickness	10 cm	10 cm	8 cm	8 cm
6	Diameter of Mouth	30 x 21 cm	20 x 20 cm	2 0x 20 cm	20 x 20 cm
7	Floor Material	no	clay	clay	clay
8	Materials	yellow clay	grey clay	yellow clay	yellow clay
9	Shape in the Furnace	square	round	square	square
10	Tuyere	2	2	2	2
11	Bamboo in Tuyere	no	1	2	2
12	Tuyere Diameter	8 cm	8 cm	8 cm	5 cm
13	Tuyere Length	15 cm	18 cm	14 cm	15 cm
14	Fluxes	no	no	exist	exist
15	Forms of Limestone	no	no	big (> 5 cm)	small (<5 cm)

Source: Research report Hartatik et al., 2019

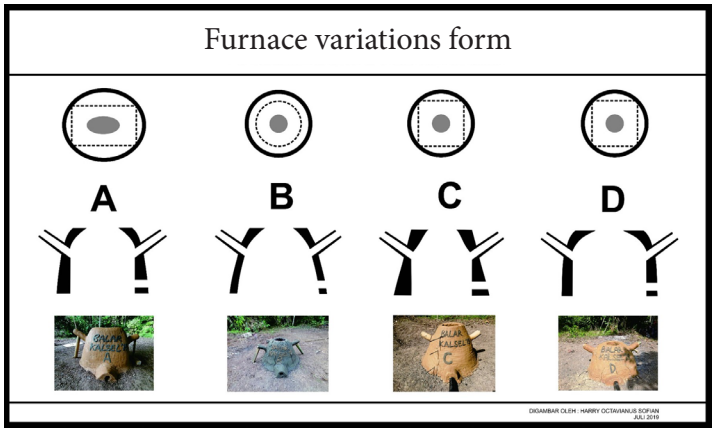


Figure 7. Furnace variation form
(Source: Author, 2019)

Table 2. Comparison clay, charcoal, iron ore and flux consumption

No.	Furnace	Clay (Kg)	Charcoal (Kg)	Iron ore (Kg)	Flux carbonate rock (Kg)
1	Furnace A	179,7	58,4	10	0
2	Furnace B	191,4	48,9	10	0
3	Furnace C	186,1	82,1	5,3	22,5
4	Furnace D	208,2	61,4	7,8	22,5

Source: Research report Hartatik et al., 2019

After conducting the experiments with iron melting furnace models, A, B, C and D for two days, several results were obtained. As for some of the initial assumptions obtained from the results of interviews with residents, there were some observations that did not match the experimental results. From interviews conducted in 2018 (see Hartatik *et al*. 2018, 32–33), one of the statements recorded was that during the iron smelting process, when the iron ore was put into the furnace, the iron ore would be thrown out of the furnace or had exploded. To prove these arguments, an experiment was made to dry and roasting the iron ore before put into a furnace, the point being to remove the water in the iron ore and creating a dry ore. This process was carried out by applying burning charcoal on top of the wet iron ore and then leaving it to dry until the burned iron ore did not contain any remaining water. Then the iron ore is pounded and put into a melting furnace.

Figure 8. Experiment process roasting iron ore
(Source: Author, 2019)

There are two different reactions that occur in wet iron ore. First, the iron ore will jump out of the melting furnace if the iron ore still contains water. Second, the increase in temperature from cold to hot accompanied a sudden decrease in water will produce kinetic energy throwing or bursting the iron thrown out of the furnace. These reactions do not happen if the iron ore has been dried before and where there is no throw or explosion of iron ore when thrown from the melting furnace. So, the true statement is, during the iron smelting process, when entering iron ore into the melting furnace, the iron ore will be thrown out of the furnace or explode will only occur if the iron ore is put in a wet or contains water.

To measure the temperature quantitatively in the melting furnace, a thermocouple functions as a temperature sensor. Thermocouples consist of various types, each with different manufacturing materials, measurement ranges, and sensitivity. For this experiment, the sensitivity of a Type S thermocouple begins at 0° C – 1,767° C, where temperatures above 1,767° C cannot be measured. Iron will melt at a temperature of 1,538 ° C and boil at a temperature of 2,800° C.

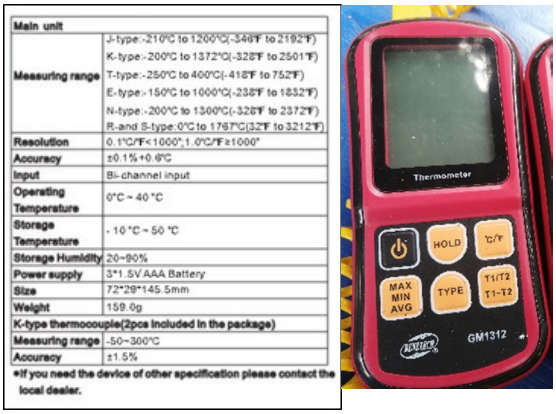
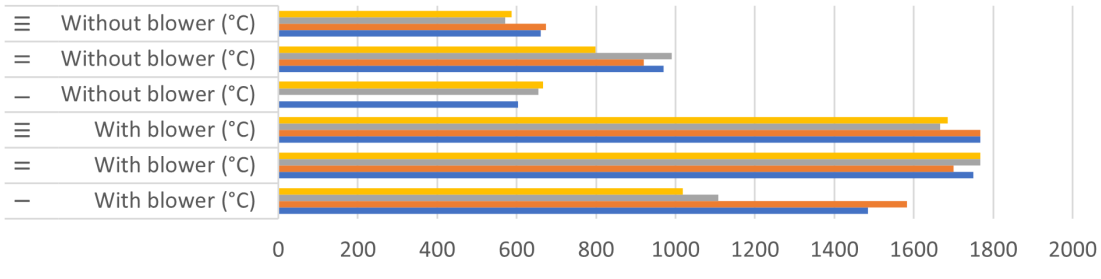


Figure 9. Thermocouple specification and device (Left source: Manual book Benetech GM 1312, right source: Author, 2019)

From the table below, (Table 3) it can be seen that the temperature comparison between melting furnaces A, B, C and D before using the blower is below 1.000° C with the highest temperature in the middle with an average temperature of 800° C, when comparing melting furnaces A, B, C and D using a blower, the temperatures are doubled above 1.000° C with the highest temperature above 1.767° C where the thermocouple can't measure the higher temperature. The use of an air pump blower is mandatory if the archaeologists want to increase the temperature in the melting furnace.

Table 3. Comparation heat furnace with and without



	I With blower (°C)	II With blower (°C)	III With blower (°C)	I Without blower (°C)	II Without blower (°C)	III Without blower (°C)
Furnace D	1018	1767	1686	666,6	797,8	587
Furnace C	1108	1767	1667	655	990,4	571,2
Furnace B	1583	1700	1767	0	920,2	673
Furnace A	1485	1750	1767	603	969,4	660

Source: Research report Hartatik et al., 2019

At the time of the smelting, there were several conditions that occurred during the experiment. Details can be seen from the comparison of the furnace condition results below:

Table 4. Experiment furnace condition results

No.	Furnace Description	Furnace A	Furnace B	Furnace C	Furnace D
1	furnace	crack	crack	crack	crack
	tuyere condition	all good but have a crack	all broken	all broken	all broken
2	tuyere with bamboo	no	no	yes	yes
3	ingot shape	irregular	irregular	irregular	irregular
4	slag form	clumping	clumping	melt	melt
5	slag on the furnace wall	exist	exist	exist	exist
6	heat more than 1538°c (melting point)	yes	yes	yes	yes
7	heat more than 2859°c (boiling point)	unknown	unknown	unknown	unknown
8	duration of experiment	4 hours 35 minutes	4 hours 35 minutes	9 hours 30 minutes	9 hours 45 minutes

Source: Research report Hartatik et al., 2019

Based on the results of the melting furnace obtained from melting furnaces A, B, C and D, several comparisons are obtained that can be seen from the table below:

Table 5. Experiment condition results for iron ore

No.	Description	Furnace A	Furnace B	Furnace C	Furnace D
1	iron ore	10 kg	10 kg	5,3 kg	7,8 kg
2	result	6,04 kg (60,4 %)	4,69 kg (46,9 %)	2, 7 kg (50,9 %)	1,7 kg (21,7 %)
3	source iron ore	Buren Temelalo	Semayap River	Buren Benangin	Buren Benangin
4	material	laterite+hematite	laterite+hematite	hematite	laterite

Source: Research report Hartatik et al., 2019

From the results, iron smelting is obtained if the source of the material affects the percentage of iron refining, this can be seen if the material from the mixture of laterite and hematite is similar, but if the materials are separated, different results will be obtained. Laterite will produce a lower iron content than hematite. The process of this iron smelting experiment attracted local interest to watch the process, as many local people did not know how to smelter iron by extraction from iron ore.

Figure 10. Locals people curiuos and watching the experiment iron process
(Source: Author, 2019)

4. Conclusion

From these experimental iron smelting furnaces research which is the first of its kind in Indonesia for the experimental archaeology for the metals research. The experiment has some conclusion, from the local people statement questioning if during the iron smelting process, from the experiment shown the iron ore will explode if iron ore is in a wet condition or contains water. The choice of materials for the furnaces was not chosen carelessly, from the comparison analysis of furnace A with furnace B, where furnace A uses yellow clay material that lasts longer during melting than gray clay. The use of bamboo left in the furnace to form the tuyere turned out to be unsuccessful in furnaces B, C and D, as the bamboo tuyere will break or separate from the furnace, the use of bamboo in the furnace not effective, more effective is the method of no bamboo usage. as furnace A where the bamboo is only used to make the tuyere shape.

The measurement results using a thermocouple in all furnaces all passed the melting point of iron at 1.538° C, it's meaning the furnace can produce metal even with simple equipment and techniques. The shape of the raw iron is irregular and clumpy and slag could be different between furnaces A and B and C and D due of the difference in the melting time of iron between four hours 30 minutes and nine hours 30 minutes, so that the longer the iron burns, the more liquid the slag will be. The duration of the smelting process affects the results of iron smelting. When viewing the existing site remains, the first refining process needs to be refined, the second process refined in order to obtain purer iron.

Archaeological experiments conducted in Indonesia are still very rare, even though experiments can answer some questions that are difficult to answer if experiments are not carried out. hope in the future there will be a lot of experimental research carried out not only on metals but also on other materials that can be done in Indonesia.

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Experiment process furnace C
(Source: Author, 2019)