Ministry of Environment and Food of Denmark
Environmental Protection Agency

Combustion of Rice Husk by use of Danish Straw Boiler Technology

Environmental Project
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Acknowledgments

This report is the result of a cooperation between PlanEnergi and:

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- *Dr. Hiroki Rai, associate professor, Akita Prefecture University*
- *Mayor Hiroto Takahashi, Ogata Mura Council, Japan*

I want to thank all the participating partners in making this project possible.

Jens Birch Jensen, March 13. 2019

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Contents

1. Dansk Resumé

Baseret på testresultaterne kan det konkluderes, at der med den danske teknologi til forbrænding af halm og med en standardkonfiguration af styring mv., under visse omstændigheder kan forbrændes ris-avner med en acceptabel effektivitet og begrænset krystallisation af silicaen.

Laboratorietestresultatet fra Dr. Rai, Akita University, er verificeret for standardkedlen mht. korrelationen af forbrændingstemperaturer, opholdstid for aske og silica-krystallisation.

Projektet har ikke været i stand til at vise en kontinuerlig drift med sikkerhed for ikke-krystalliseret aske, og det resterer stadig at finde kontrolparametre for automatisk at kunne optimere forbrændingen til minimal krystallisation i stedet for optimal forbrænding mht. virkningsgrad og røggasemissioner, idet der ikke findes mulighed for on-line målinger af krystalliseringen.

For at opfylde målsætningen for testprojektet er det nødvendigt at udføre yderligere test og forbedre nogle af de udførte tiltag for at optimere projektet.

Anlægstilpasningerne er primært relateret til askens tilbageholdelsestid inde i forbrændingsrummet på risten. Reduktion af opholdstiden kan opnås ved at øge bevægelsen af asken på risten, enten ved at øge hastigheden eller en forkortelse af ristens forbrændingszone. Endvidere kan temperaturreguleringen på risten forbedres ved at opdele forbrændingszonen i 3 zoner, hver med separat kontrollerbare forbrændingsluftmængder, men dette leveres normalt hovedsageligt ved kedler over 500 kW eller derover. På de mindre kedler gør ristens størrelse det umuligt at opdele i flere adskilte zoner.

TwinHeat-kedlen kan optimeres til forbrænding af ris-avner ved rekonstruktion af forbrændingsrøret for at adskille aske fra forbrænding af gas og ved at indføre et effektivt askefjernelsessystem, hvorved forbrændingen kan gennemføres med høj temperatur i meget kort tid.

Begrænsningerne i mængderne af tilgængelige ris-avner og den begrænsede erfaring med præcis, hvilken opstilling af kontrolparametre der vil resultere i ikke-krystalliseret aske, har været en stor udfordring for projektet.

Ikke desto mindre er det med relativt høj sikkerhed vist, at den måde, hvorpå den danske kedel styres, gør det muligt at tilpasse teknologien til forbrænding af ris-avner uden silica krystallisering af asken og med en rimelig høj effektivitet, selvom nogle ændringer i konstruktionen af ristbevægelse og forbrændingsluftsystem kan være nødvendigt.

Generelt vil det være nødvendigt at der etableres en stationær testenhed til kontinuerlig afprøvning af forbrændingen for at foretage egnede tests og opnå den nødvendige erfaring til at indføre optimering af kedlen. En udfordring heri er, at der ikke findes en enkel metode til on-line eller on-site måling af krystalliseringen af asken. Det er således ikke pt. muligt umiddelbart at få verificeret om en givet test er succesfuld eller ej.

Derfor anbefales det at oprette et pilotanlæg på et lokalt risproduktionsanlæg med mulighed for at gennemføre længevarende drift under samme driftsforhold, med det formål, at få fastlagt en målemetode, således at krystalliseringen af asken kan registreres løbende.

2. Summary

Based on the test results it may be concluded that the Danish technology for combustion of straw and the standard configuration of control etc. under certain circumstances can perform combustion of rice husk with acceptable efficiency and little crystallization of the silica.

The laboratory test result of Dr. Rai, Akita University, is verified at the standard boiler regarding the correlation of combustion temperature, retention time of ash and the silica crystallization.

The project has not succeeded in showing a continuous operation with certainty of non-crystallized ash and it still remains to find the control parameters to automatically optimize the combustion for the minimal crystallization.

To fulfil to objective of the test project it is necessary to perform further test and improving some of the measures introduced to optimize the project.

The measures are primarily related to the retention time of the ash inside the combustion chamber on the grate.

Reduction of the retention time can be achieved by increasing the movement of the ash on the grate, either by increasing the speed or cutting of the length of the grate.

Furthermore, the temperature-control on the grate may be improved by separating the combustion zone in 3 zones, each with separate controllable air flows, but this is mainly provided at boilers above 500 kW or bigger. On the smaller boilers the size of the grate makes it impossible to divide in more distinct zone.

The TwinHeat Boiler may be optimized for combustion of rice husk by reconstruction of the combustion pipe in order to separate ash from the combustion of gas and by introducing of an efficient ash removal system, hereby introducing a high temperature combustion with a short retention time of the ashes.

2.1 Project background

The most frequently used combustion technology for the incineration of Rice Husks is today the gasification plant. However, today no suppliers can provide commercialized, low-cost, standard solutions based on the gasification system. As far as is known, no commercial solutions are available outside the power plant industry, where both a high utilization rate of the energy content and ash production, which can be recycled as a fertilizing product can be demonstrated.

It is our assumption, based on the good experience in Denmark with the incineration of straw and cereal residues, that with a specially adapted management and perhaps minor adjustments of the plants in terms of supply and control of combustion air and the removal of the large quantities of ash, the Danish technologies could provide a breakthrough in the utilization of this resource for heat production and fertilizer, partly in the rice processing industries (drying, etc.) and partly for use in district heating production.

In many places in Japan, rice husks are today a waste product which, if it cannot be used as a refill for construction works etc., must be disposed of in filling areas.

When used for incineration, the energy content can be utilized like the ash can be applied for fertilizer purposes. This saves large quantities of other fuels (mainly oil and natural gas) and commercial fertilizers.

A controlled combustion process can avoid harmful silica crystals in the ashes which, if inhaled in conjunction with handling, may cause silicosis or similar lung damage (similar to asbestosis) and prevent its use as fertilizer.

2.2 Project execution

The project is based on tests performed at two Danish boiler manufacturing companies Linka A/S and Twin-Heat A/S.

As there is no rice production in Denmark it has been necessary to import rice husk from Japan for the test. The test program has been limited to short time tests due to:

- Limited financial and technical resources
- Limited amounts of the rice husks

and the fact that the only known way to verify the content of crystallized silica is performing an X-ray analysis of the ash. It has not been possible to have these analyses done in Denmark.Therefore the ash samples have been set to Japan for analyses done by Dr. Hiroki Rai, Akita Prefectural University.

LINKA Boiler

During the tests of the LINKA boiler the following issues were investigated:

- Amount of excess air (air for cooling of combustion temperature)
- Flue gas recirculation for cooling of combustion
- Grate speed regulation to optimize the retention time on the grate for short time of high temperature and satisfaction of efficiency
- Load of the boiler, i.e. the amount of rice husk on the grate

TwinHeat Boiler

Several short time tests were performed with the TwinHeat Boiler and ash samples forwarded for analysis by Dr. Rai at Akita University.
The tests at TwinHeat boiler also showed relatively high crystallization of the ash.

Ash samples were taken during the test both from ash container and taken from the combustion pipe before ejection of the ash.

The ash seems to crystallize during its way to the extraction due to the high radiation temperature inside the combustion pipe. The ash temperature itself was relatively low.

Due to the fact, that combustion takes place only in the combustion pipe, it is not possible to adjust parameters for controlling the temperature

To give successful combustion without silica crystallization of the ash the boiler needs further development to reduce the retention time of the ash inside the combustion chamber or to shield the ash from the combustion of the gasses which implies a high radiation temperature to the ash in the bottom of the combustion pipe.

The tests are described, and results presented at the appendices of this report.

2.3 Project results

The combustion of the rice husk with the Danish straw combustion technology has been very successful. The combustion can be performed with very high efficiency and low emission rate of NOx and CO.

The test results have proven a high similarity in the commercial boiler plant to the laboratory test results of Dr. Ray indicating the correlation between the temperature of the combustion (especially the temperature of the ashes) and the retention time at the actual temperature level in forming the crystallized silica.

It is also proven that it is possible at the LINKA Boiler to set up the combustion with a resulting crystallization and a reasonable combustion rate (total efficiency of combustion).

The acceptable combustion can be achieved through to right adjustment of:

a) Combustion temperature
b) Retention time of ash in combustion

These parameters are readily adjustable at the standard Linka boiler for combustion of straw etc.

Re a) The combustion temperature can be controlled by

- Adjusting the excess air

The combustion fans are speed-controlled in accordance to fuel input and setpoints may be set individually. Excess air is measured by the oxygen content of flue gas

- Regulation of the combustion air distribution of the combustion zones (3 zones)

Re b) Retention time,

- The retention time can be controlled by adjusting the performance of the grate movement which may be set for different speed and travel length.

The big challenge of the project has been, that we have no parameter accessible to continuously measure the actual crystallization. So practically the tests have not resulted in a usable set of combustion parameters that will ensure a stable combustion without silica crystallization of the ash.

2.4 Recommendations

The limitations of the amounts of rice husk and the limited experience of exactly which set-up of controls will result in non-crystallized ash has been a big challenge to the project.

Nevertheless, it is shown with relatively high certainty that the way the Danish boiler is con-trolled makes is possible to adapt the technology to the combustion of rice husk without silica crystallization of the ash and with a reasonable high efficiency though some changes in the construction of grate movement and combustion air system may be necessary.

In general, to conduct proper tests and achieve the necessary experience to introduce the optimization of the boilers a local stationary test unit must be established to continuous test of the combustion.

Therefor it is recommended that a pilot plant is set up at a local rice production plant, with the possibility of performing a long-term steady state test.

For the smaller boiler from TwinHeat this test may be performed in Denmark as the amount of Rice Husk needed is smaller.

The test programme should include:

- Establishment of a test boiler setup including an extended number of measurement point
- Further investigation on the correlation between measurable parameters and the crystallization process
- Development on a on-site determination method for crystallization of the ash

3. Project description

<u>Purpose of the project</u>:
Adaptation/further development of Danish technology for biomass-incineration plants for the incineration of rice-husks and the preparation of verified evidence of the non-crystallizing combustion

3.1 Background

During a couple of years Planenergi collaborated with the Danish Embassy in Tokyo and the local consulting firm Institute for Sustainable Energy Policies, ISEP, to introduce renewable energy and district heat-ing in the Japanese energy system.

A specific project that is being worked on is the establishment of a district heating network in a smaller town, Ogata-Mura, Akita Province, where they want to exploit a local resource in the form of Rice Husks. The utilization of the Rice Husk for heating purpose will help reducing the issue of Rice Husk as Waste simultaneous with the reduction of fossil fuels for heating purposes.

There is a huge amount of this biomass resource in Japan, as a large rice-producing country, which is currently not exploited in rice production, but is used as a land filling, and may pose a waste problem in some areas.

Rice Husks as fuel poses some relatively big challenges in relation to combustion as it contains up to 20% ash (straw contains about 5% by comparison).

At the same time, the main proportion of non-combustibles are silica compounds, which have a very low crystallization and ash melting point, so likely crystallized silica is formed, which are considered damaging for health, at the level of asbestos fibers etc. and prevent the use of the ash as nutrient.

Because of these aspects, the use of Rice Husks for combustion with heat utilization and re-use of the ashes is very limited both in Japan and many other rice-producing countries.

Today the main trend for combustion of Rice Husk is use of gasification but this technology tends to have high investment and maintenance costs and be relative sensitive to changes to running conditions. Therefor it is mainly used for constant running plants.

If the combustion issue is solved without forming of crystallization of the ash there is a market for that technology worldwide.

3.2 Project description

Denmark has a very long experience in using straw and husk from cereals, grasses etc. as a fuel source and it seems evident to investigate if the technology and the experiences can be used for the combustion of Rice Husk.

Unfortunately, Denmark has no rice production and no experiences with the analysis of ash crystallization because this is not seen a problem in the utilization of ash from combustion of straw etc.
Based on test material submitted from Japan, combustion tests are carried out on 2 technologically different typical Danish plants;

A) A moving step-grate furnished as a straw or wood chips fired plant (LINKA Energy A/S)
B) Burner Combustion as in a wood pellet combustion plant (TwinHeat A/S)

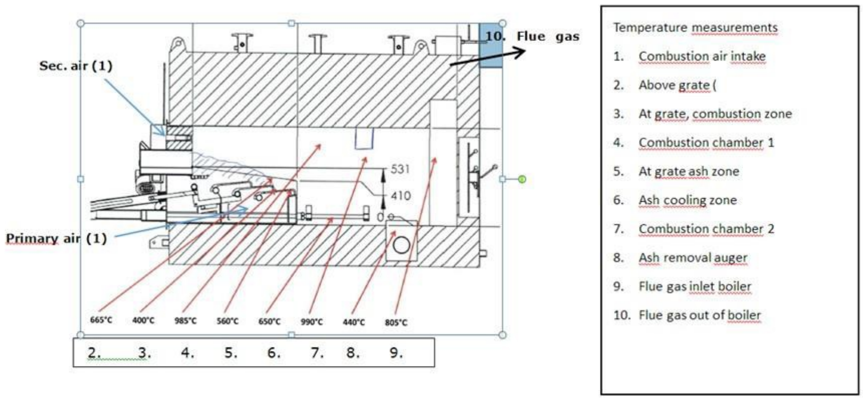


Fig. 1: Principle drawing of Linka push/step grate boiler plant.

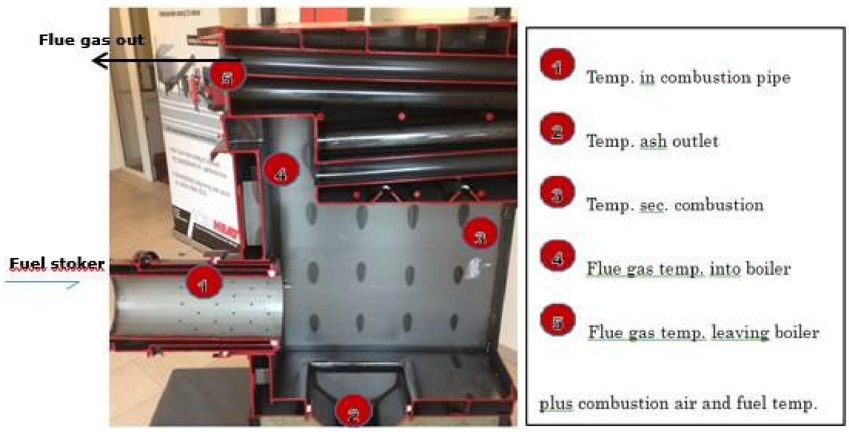


Fig. 2: TwinHeat pellets burner and hot water boiler

During the test, temperature conditions, combustion, etc. are surveyed and monitored.
Ash samples are taken for crystallization analysis.

The plants are adjusted and, if necessary, adapted to the special combustion conditions.

The objective of the project is to show the probabilities of performing combustion of Rice Husk with

- A reasonable combustion efficiency above 85 %
- A minimum of crystallization of ash

4. The Linka Boiler

The Linka Boiler used for the test is a standard Danish boiler with a moving step-grate. The combustion air is divided into 3 zones of primary air and secondary air supplied through nozzles in the boiler front-plate.

The combustion test showed, that if combustion is optimized for low excess air and low CO emission i.e. high combustion efficiency, the combustion temperatures will be too high, and crystallization of the ash will occur. Adjusting the volume of combustion air is possible to control the combustion temperature and reduce the amount of crystallization.

4.1 Preliminary test results (2017 and January 2018)

The results (see fig. 15, 16 and 17) shows falling crystallization during the test by adjusting excess air, fuel input i.e. The X-ray analysis of the bottom ash shows results down to 800 cps, indicating that with further optimization it is likely to achieve a combustion temperature where no crystallization will occur.

The results for fly ash show higher degree of crystallization and it may be necessary to separate the ash fraction in bottom ash and fly ash and only use bottom ah as fertilizer. The fly ash represents only a smaller portion of the ash volume (1-2 %).

During the test it was observed that adjustment of the temperature in the combustion chamber was easy and the time to achieve balance of the combustion was very short.

It is suggested that another test series with adjustments of the combustion air is performed.

The laboratory test by Dr. Rai showing the connection between temperature and time was approved by the test results of the test on the commercial boiler operation.

It seems likely that a reasonable level of crystallization will be achieved if the temperature in-side the combustion chamber is held low enough by operating with a high excess air level and controlling the combustion air for the 3 zones.

The high level of excess air will cost at loss of efficiency through flue gas loss and unburnt carbon in the ash.

The emission limits og particles and NOx will be fulfilled.

4.2 Second test round results (September and December 2018)

At the test performed in September 2018 the speed of the grate was increased by changing the drive from electric to hydraulic.
Also, a test with flue gas recirculation was performed but prevented the ignition of the rice husk.

The combustion of different Rice Husk from different bags seemed to be different. For some of the bags the ignition was very bad, and the combustion was not started until the middle part of the grid resulting in a very short combustion zone. The crystallization at this combustion showed very low crystallization, indicating that a short retention time prevents the crystallization.
In general, the increasing of the grate movement reduced the silica crystallization remarkable.

5. The TwinHeat Boiler

The Twin Heat Boiler has a combustion tube where the combustion is performed. Afterwards there is a flue gas tube boiler for regeneration of the heat.

To be able to operate with the high ash content of Rice Husk the combustion tube has been developed with an ash-scraper for transportation of the ash through the tube to the ash screw.

The boiler has been supplied with automatic ash removal system. The combustion test per-formed on the TwinHeat Boiler showed significant crystallization of the ash.

5.1 Test results

Ash samples from preliminary burnings in October 2017 and during the test on January 30th was analyzed. The results of the analyses are shown in appendix 4.

It was assumed, that if the time the ash was inside the combustion tube was sufficiently short, it might nor crystallize.

Ash samples taken out of the combustion tube showed anyway relatively high content of crystallization. The reason is likely because the ash is not removed fast enough from the combustion pipe. Because of the very high combustion temperature the retention time must be very short to avoid the crystallization. This indicates that the ash removal system must be improved without changing the control of combustion air.

To achieve the combustion without crystallization of the ash, moderations of combustion tube and ash removal system is needed.

To give successful combustion without silica crystallization of the ash the boiler needs further development to reduce the retention time of the ash inside the combustion chamber or to shield the ash from the combustion of the gasses which implies a high radiation temperature to the ash in the bottom of the combustion pipe.

6. Additional analysis on straw combustion

For comparison, ash samples from a Danish straw combustion (wheat straw) were taken and analyzed for silica. The ash sample was achieved from a typical Danish straw boiler plant supplied with a step grate furnace and a hot water boiler.

The bottom ash showed remarkable low crystallization between 580-and 1000 cps while the analysis of the fly ash showed quite high values.

Please remark that the plant was adjusted for low CO and NOx emissions and no special actions were taken to reduce crystallization.

The reasons for the difference to the combustion of rice husk is unknown but the following may be noted:

- The silica content of wheat straw is much lower than Rice Husk
- The ash removal system included a waterfilled conveyor whereby the ash is cooled down immediately after leaving the grate.
- The combustion of straw is also performed with low temperature of the grate to avoid clinkers in the ash.

APPENDICES

Test results

7. Appendix list

Appendix 1: Rice Husk Combustion test specifications
Appendix 2: Preliminary test on Linka Boiler Dec. 14th-2017
Appendix 3: Preliminary test on Linka Boiler Jan. 30th-2018
Appendix 4: Preliminary test on TwinHeat Jan 31st-2018
Appendix 5: Second test round on Linka Boiler, Sept. and Dec. 2018

Appendix 1. Specification of the Rice husk Burning test

Rev. 2018-04-04

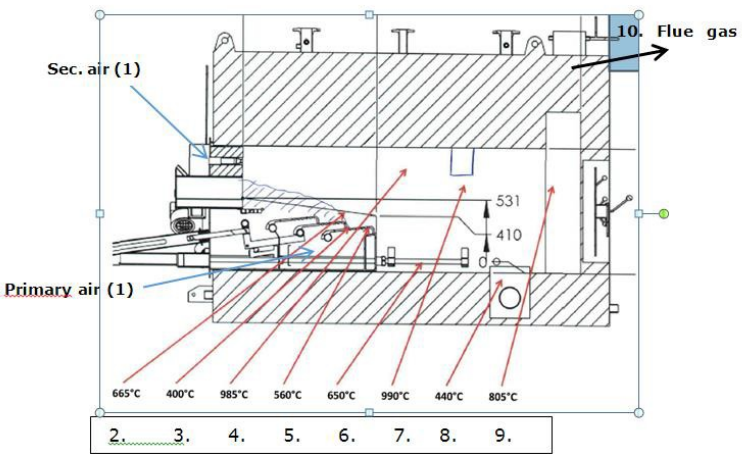
1. Testing companies

The companies which conduct the test are Linka and TwinHeat.

2. The boilers used for the test

Test are made on the following ready-made boilers

- **Linka, push/step-grate with stoker**
-
- Boiler capacity approx. 400 kW on wood pellets
  Combustion will take place along the movement of the fuel on the grate.
  The temperature levels on the grate will be controlled by means of the combustions air volume and the amount for primary and secondary air. The temperature levels shown on figure 1 are achieved by burning wood pellets.



Temperature measurements

1. Combustion air intake
2. Above grate (
3. At grate, combustion zone
4. Combustion chamber 1
5. At grate ash zone
6. Ash cooling zone
7. Combustion chamber 2
8. Ash removal auger
9. Flue gas inlet boiler
10. Flue gas out of boiler

Figure 1 Principle drawing of Linka Push/step-grate boiler

- **TwinHeat pellets burner**
-
- Boiler capacity 20-60 kW on wood-pellets

  The combustion takes place inside the combustion tube at high temperature and short time. The ash will be pushed to the ash removal screw by means of the fuel input eventually assisted by an ash-pusher mounted in the bottom of the combustion pipe.

  The ash retention time at high temperature is expected to be short.

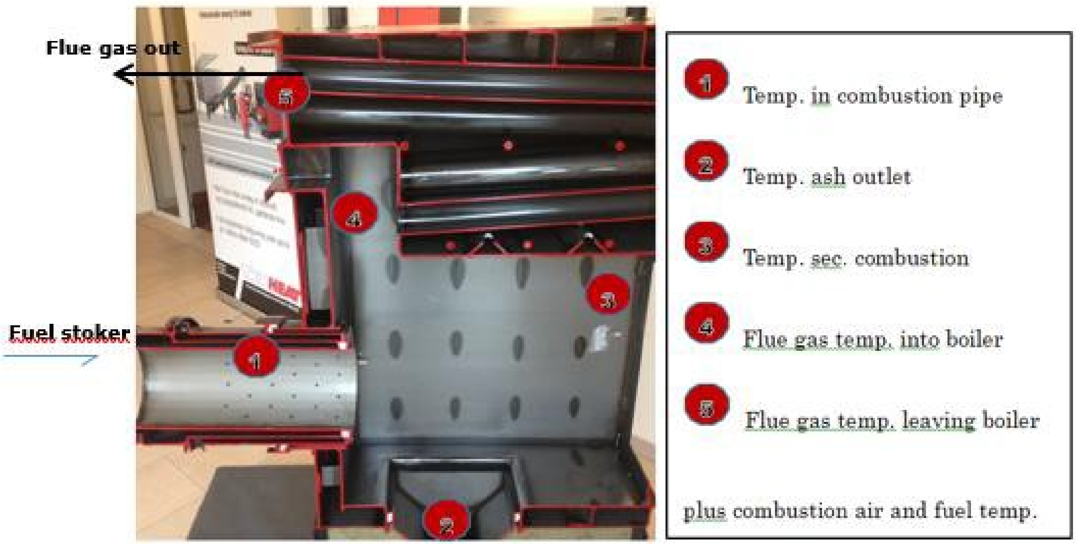


Figure 2 Twin Heat pellets burner and water boiler

3. Required conditions for the test

- Mixing rice husk with other type of fuels are prohibited except when you start up and warm up the boiler. After the boiler attain normal condition, no other fuels can be mixed.

  This means a boiler which cannot burn rice husk alone is excluded from this test.
- During preliminary tests different settings of the combustion will be tested until the optimal settings is found. During preliminary tests a number of ash analyses will be taken.
- During preliminary test the maximum and minimum load (heat power) is determined for the specific boiler.
- The final test is made during minimum 2 hours operation on stable conditions and with the chosen settings.

4. Measurements to be made

The followings are measured during the test at an appropriate time interval:

(1) The amount of rice husk input per unit time is estimated by weighing the fuel input. Because of the unaccountable fuel amount inside the stoker and in feed-in system at a specific time, this can only be estimated roughly.

(2) The following temperatures is observed:
- temperatures inside the boiler at (1) burning chamber, (2) secondary chamber,
- temperatures outside boiler: (3) boiler flue gas exit, (4) combustion air, (5) rice husk and (6) ash temperature at outlet.

<u>Other Measurements</u>

(3) Retention time of rice husk in the boiler (from rice husk input to ash output)
(Only estimated roughly because of the extension of the ash volume inside the system).

(4) Amount of produced ash during the test

(5) The amount of ash can be measured by weighing the total amount of produced ash after the test including the volume cleaned out from inside of boiler and ash system

(6) Amount of produced heat measured by the difference between water temperature and its volume per unit time (measured by heat meter at boiler)

(7) **Sampling of the ash:** Ash need to be collected regular intervals (every 15 minutes) and stored properly for the later analyzes.

After performance of the test, analyses of a representative sample of rice husk and the ash samples taken is performed as:

- Rice Husk sample

calorific value, moisture content, silica, mineral salts, C, H, O and ash content of

- Ash samples

ratio of crystallization of silica in the ash and content of unburned in ash

5. Documentation

- Specs of the boiler, calculation of combustion air and flue gas volumes
- Date and time of the test
- Photos during the test
- Test results showing time and measurement data during the test

6. Time Schedule

A. Phase 0 April - May 2017

- Transport of Rice Husk

B. Phase 1, initial testing at adjustments June 2017-May 2018

- preliminary tests at boiler manufacturer,
- determining of heat load and settings of combustion parameters
- finalizing description of verification and success levels

During initial test and adjustment of the combustion it is not required to fulfill all measurement as shown above.

C. Phase 2, Verification and documentation June-July 2018

- test performed and documented by independent institute
- analyzes of rice husk and ash
- preparation of project report

D. Phase 3, Communication of results

- preparation of project presentation documents in English and Japanese
- presentation of result at meeting(s) in Japan

7. Issues in rice husk burning

Rice husk is in rich with silica contents which is notorious for producing clinker in burning chamber in the boiler to inhibit its proper operation. Since silica content in rice husk is over 20% in weight and it won’t vaporize, it will end up with 20% or more ashes after burning.

When rice husk is incinerated at high temperature, this silica will crystalize, which International Agency for Research on Cancer (IARC) categorizes as carcinogenic substance (i.e., inhaling its dust causes health risk). In Japan, its content in the ash has to be below the standard value set by the Japan Society for Occupational Health to ensure occupational health of workers.

Therefore, it is necessary to establish the burning method not to produce this harmful crystalline silica to utilize this underused local resource.

Burning rice husk

→ **Burning efficiency / heat conversion efficiency**
It affects heat output per unit time, and heat supply per unit amount of fuel.

→ **Production of Clinker**
It affects frequency of boiler maintenance, longevity, and associated cost.

→ **Burnt ash**
More than 20% in weight of ash is produced, as compared to less than 1% from wood pellet, which major content is silica, essential nutrients for rice growth.

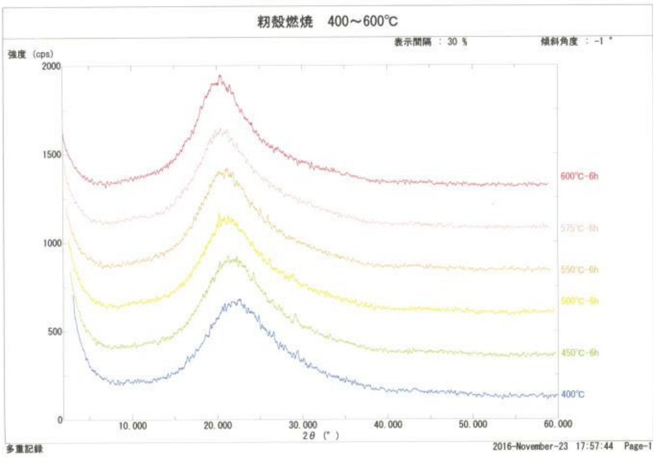
⇩

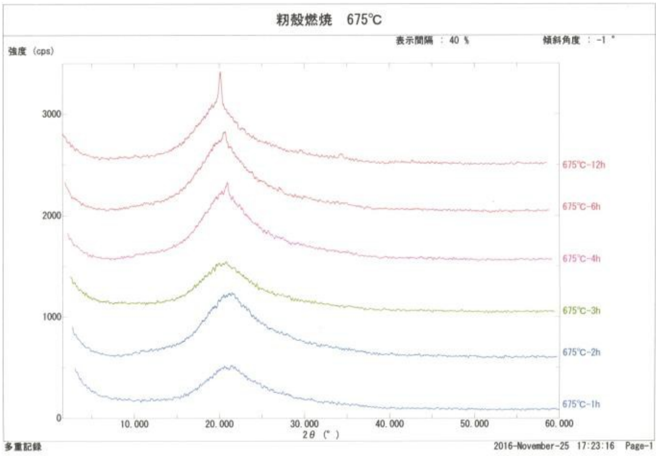
Major problem is production of crystalline silica.

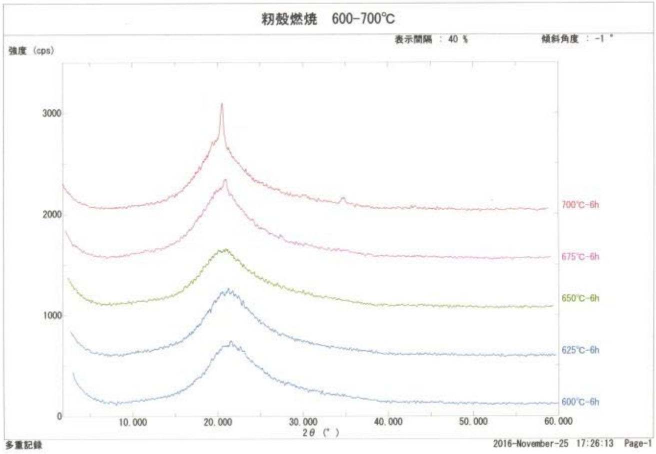
Seeking for a method not to produce crystalline silica

Preceding studies reported that burning rice husk at a certain temperature causes eutectic reaction: for instance, at 743 °C or over with potassium (K) and at 782 °C or over with sodium (Na) [Osaka University].

However, we have conducted detailed test for varying temperature (400 °C to 700 °C and burning time (1 to 12 hours) since reported temperature of crystalline silica production from rice husk burning varies depending on burning duration







各温度におけるもみ殻燃焼灰の結晶性の評価

籾殻燃焼　400℃～600℃； 400、450、500、550、575、600℃で6時間燃焼籾

殻燃焼 600℃～700℃；600、625、650、675、700℃で6時間燃焼

籾殻燃焼 675℃；675℃で1、2、3、4、6、12時間燃焼

The result of the above combustion tests showed that threshold temperature for crystalline silica production is 675 ℃ but it does not crystalize for the first 3 hours at the same temperature. This means that crystallization of rice husk ash occurs at a high burning temperature but it is also time dependent.

It is suggested that among the testing condition that we have conducted this time, (1) the ash did not crystalize at 650 ℃ even if the ash was left in the burning chamber for a prolonged time but (2) crystallization occurred slowly at 675 ℃ or above. This is also in line with the fact that IHI Environmental Engineering's boiler does not produce crystalline silica with a very brief burning time at over 1,000℃ burning temperature.

In conclusion, we need to consider

(1) amount of fuel,
(2) air supply,
(3) the amount of recovered heat, and
(4) burning duration or time, in order to avoid crystalline silica in ash. The following combustion conditions are assumed to be ideal to avoid crystalline silica production in rice husk ash:
- (a) to control burning temperature below 650℃, or
- (b) to shorten burning time and retention time of the ash in the chamber if it is burnt over 675℃.

Appendix 2. Preliminary Comb. of Rice Husk - Dec. 14th, 2017, Linka Energy A/S

Report prepared by Linka Energy A/S and Jens Birch Jensen, PlanEnergi.
TEST REPORT
Incineration of 'rice husk' d. 14.12.2017 at Linka Energy A/S

TEST DATA
• Linka 400 kW (Nominal heat power on dry wood chips) boiler with moving grate
• 3-hour test incl. commissioning
• An average of 236 kW is produced

Average flue gas data for 1-hour operation	
O2%	7.28%
CO	185.75 ppm
NOx	217.6 ppm
Flue gas temperature at chimney	136.5 ° C

- Estimated efficiency based on measured O2 and flue gas temperature is approx. 91.5% (loss in ash – unburnt and temperature – and radiation loss not calculated)

- Temperatures measured in a box:
  - 1013 °C directly in the fire on the grate
  - 825 °C on the grate during final combustion
  - 800 °C in the flame over the grate
  - 775 °C at the boiler outlet

TEST RESULTS
During the test, approximately 3 hours of continuous operation were run including adjustments.

The boiler was adjusted for optimal combustion regarding combustion efficiency and emissions of CO and NOx.

After completion of the adjustment, 236 kW were produced approx. 60 % of heat capacity for wood chips/wood pellets.

The large amount of ash causes the grate to run continuously to transport the ash on the grate to the ash removal screw. The ash system must also be dimensioned to the large amount of ash.

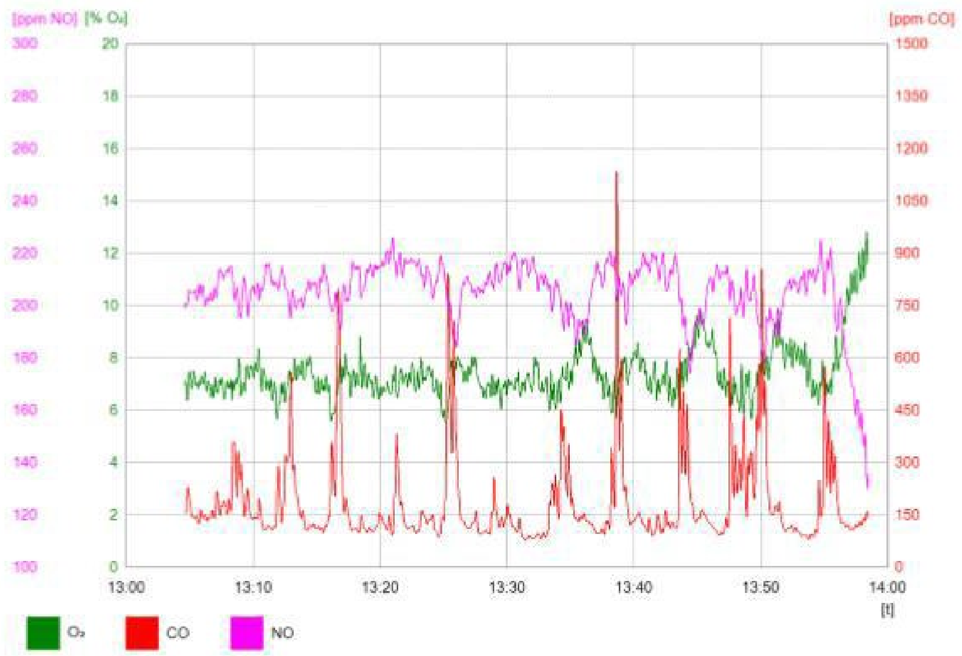
The fly ash (ash from multicyclone) constitutes a very small part of the total ash quantity - below 1%.

There will not be build-up of ash / slag in the boiler due to the large movement of the grate. The grate parts were completely clean after the end of the test.

The material is not 100 % burned, as it was found that the ash at the outlet was still glowing. Note the glowing area at the bottom of the image below.

Below are shown curves for CO, NOX and O2 measured over a period of approximately 1 hour.
These measurements can be expected to be improved by further tests, as in the present test, there were problems with the fuel supply.

Measurement	
Start	14-12-2017 13:04:37
End	14-12-2017 13:58:29
Instrument	testo 350
Serial number	02331469



Ash analysis performed by Dr. Rai, University of Akita

Dr. Rai has analyzed Linka's sample by X-ray and NC analyzer.
The result of multicyclone ash (Fly ash) by X-ray were higher value of cps (3500-4000cps).
They were named in デンマーク①-1 and ①-2 in Japanese.
It was suggested that the maximum cps value was 5500-6000 (i.e. 1 hour combustion at 1000 ℃).

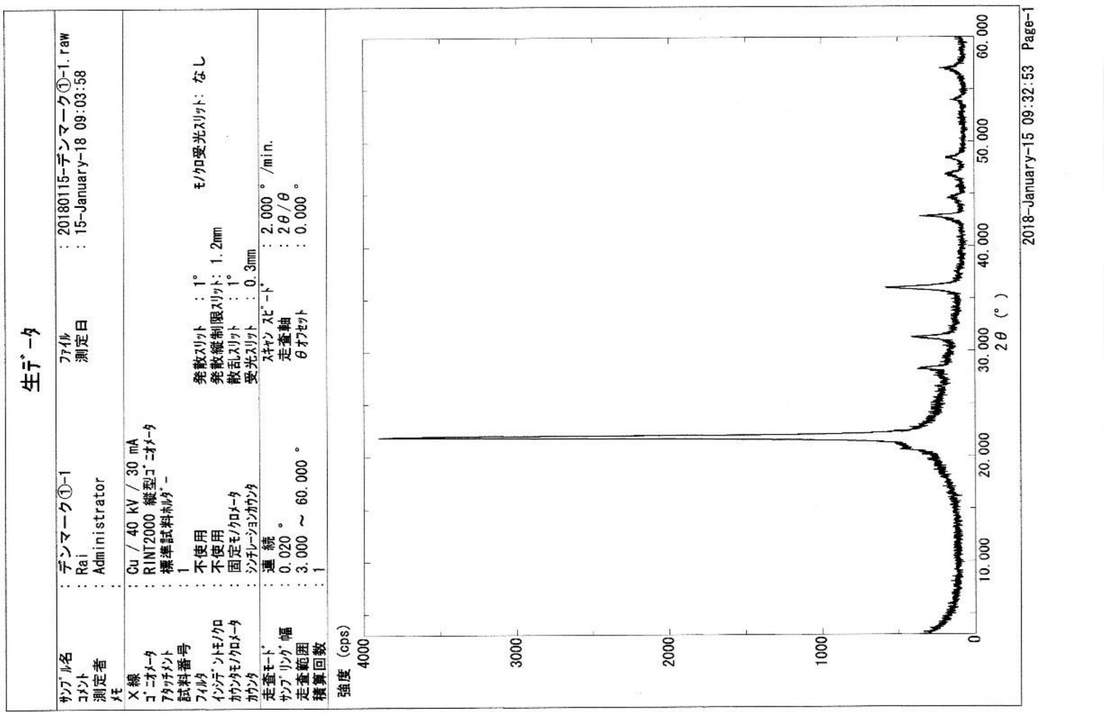
The value of the cps was increased depending in the combustion time in each steps of temperature and the cps value could be used quantitative parameter.

The results of Grate ash were lower. They were named in デンマーク②-1 and ②-2.
The sub-number was replicate. The results for the grate ash was as shown in Fig. 2 approx. 1100 cps.

In the case the value of 6000 cps was defined in 100% crystallization, the 1100 cps was suggested to be 15% crystallization.

The Total C was 4.25% in multicyclone ash and was 9.40% in Grate ash (i.e. efficiency loss of approx. 2 %).
The percentage of combustion loss were suggested to be around 10%. Including radiation heat loss of 0,5 % the total boiler efficiency may be estimated to 87,5%.

Figure 1: X-ray analysis result no 1-1, Fly ash



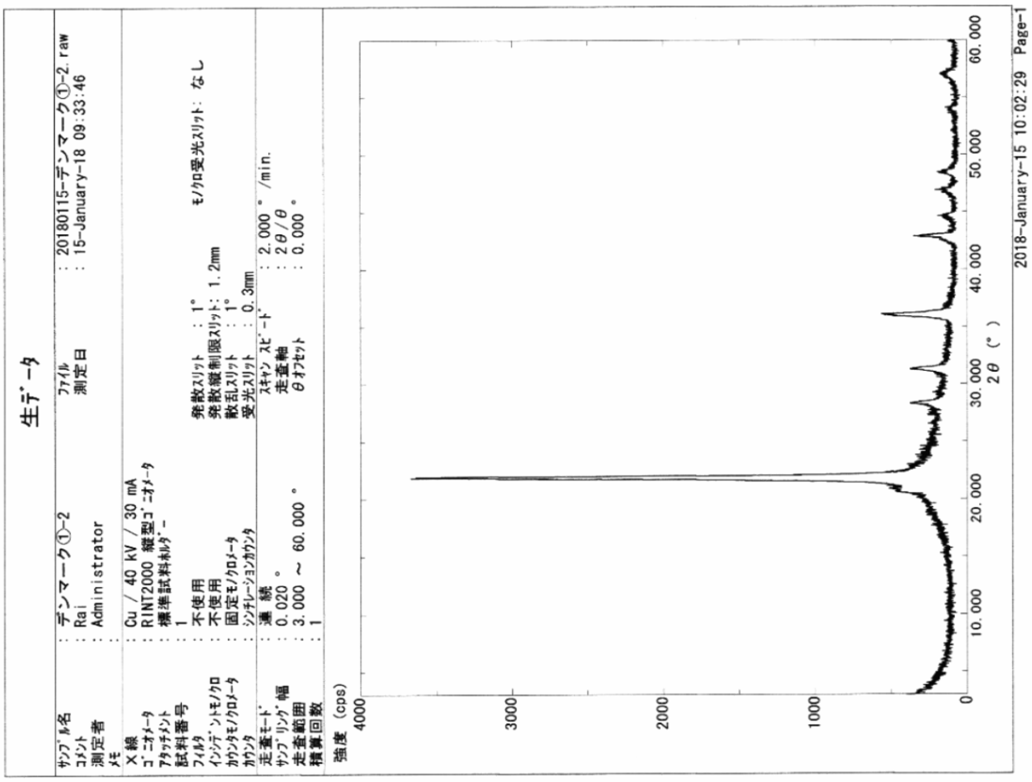
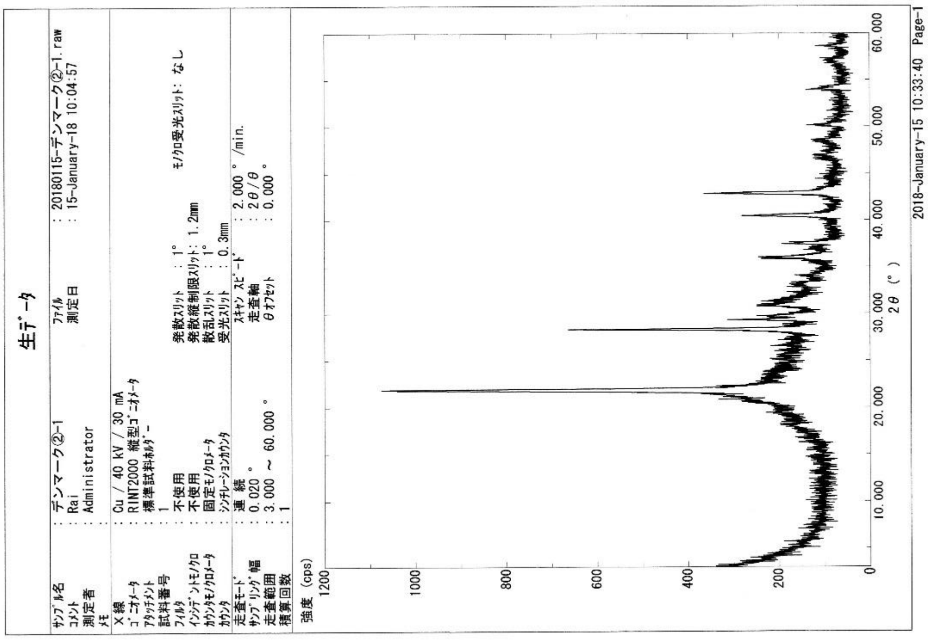
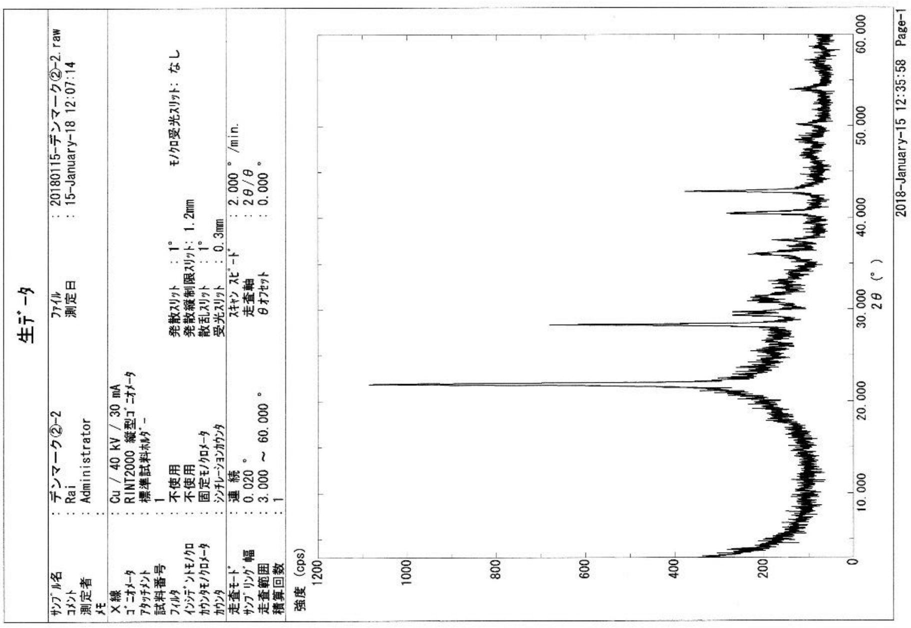


Figure 2 X-ray analysis results of grate ash





Appendix 3. Preliminary Comb. of Rice Husk - Jan. 30th, 2018, Linka

Report prepared by Jens Birch Jensen, PlanEnergi.

TEST REPORT

Incineration of 'rice husk' 30.01.2018 at Linka Energy A/S

- TEST DATA
  Linka 400 kW (Nominal heat power on dry wood chips) boiler with moving grate
- The boiler has 3 primary combustion zone which may be individual adjusted
  The grate movement speed may be adjusted. Due to the amount of ash compared to woodchips the grate is running at max. speed.
- Test running from 09:30 – 14
- Boiler was started and running on Rice Husk from the morning and at operating condition at the start of the test
- An average of 225-250 kW is produced
  Flue gas temperatures measured to 150-165 °C

TEST RESULTS

During the combustion test the load and amount of combustion air was adjusted.

1) 9:40 to 10:40 (optimized combustion)
   Load approx. 225-250 kW

O2 %	6-8 %
CO	145 ppm (50-400 ppm)
NOx	220 ppm

CO emissions were influenced by the opening of the boiler to inspect combustion and take out ash samples.

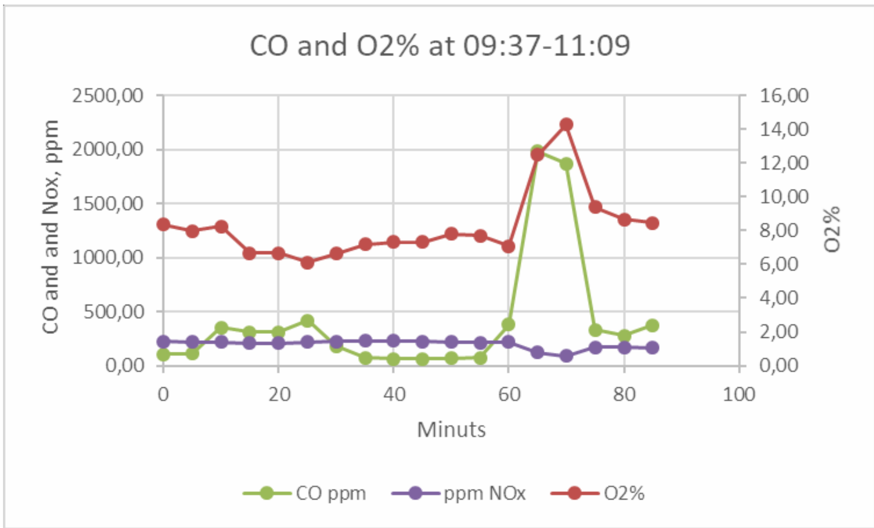
Temperatures measured
- lower part of grate 95 °C
- in secondary combustion air above combustion zone 800 °C
- In combustion zone (in fuel) 1000 °C

At 10:40 the boiler was opened to take ash samples and temperature measuring
10:50 to 11:10 (optimizing temperature level on grate)

2) Load reduced 20% to approx. 175 - 200 kW

O2 %	8-10 %
CO	1150 ppm
NOx	220 ppm

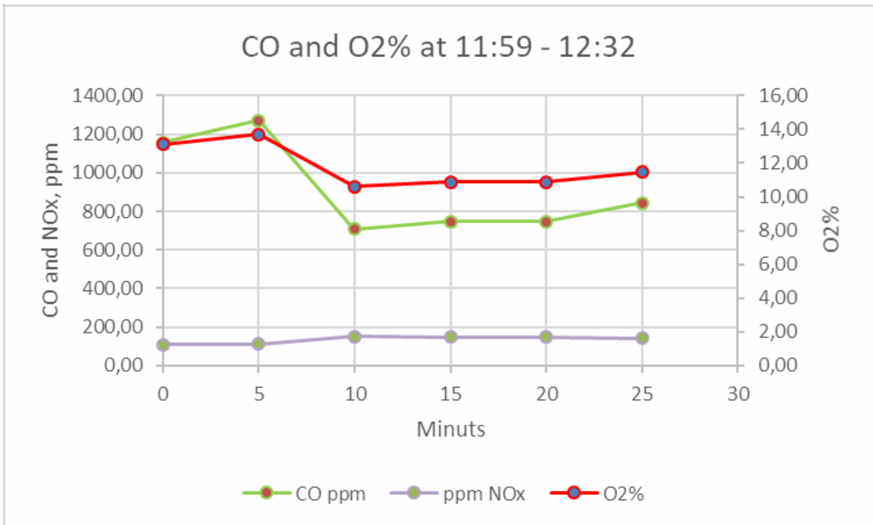
Temperatures measured
- In combustion zone (in fuel) 965 °C
- lower part of grate 95 °C
- in secondary combustion air above combustion zone 700 °C



3) 12:00 to 12:30 (optimized combustion)
Load reduced to approx. 170 kW

O2 %	11-12 %
CO	950 ppm
NOx	175 ppm

Temperatures measured
- in primary combustion zone (in fuel) 800 °C
- upper part of grate (30 cm downside grate) 700 °C
- middle part of grate (70 cm downside grate) 450 °C



After completion of the adjustment, 236 kW were produced approx. 60 % of heat capacity for wood chips/wood pellets.
The large amount of ash causes the grate to run continuously to transport the ash on the grate to the ash removal screw. The ash system must also be dimensioned to the large amount of ash.

Fly ash will amount to approx. 1 % of the total ash amount and it will be possible to separate fly ash and bottom (grate) ash if necessary.

Ash analysis performed by Dr. Rai, University of Akita

Dr. Rai has analyzed Linka's sample by X-ray and NC analyzer.

Danish combustion ash analysis						
Visit to regional heat supply facility						
Linka Biomass Boiler 400 kW test Plant at LINKA work shop						
Rice Husk Combustion test, 2018.01.30					Crystallization	
					CPS	%
Initial Condition - Boiler optimized for minimum CO emission						
	Fly Ash	Husk Temperature during combustion is 1000 °C	1	fig. 1	1400	
		Upper furnace, upper part 950 °C (increased air)	2	fig. 2	1375	
	Bottom Ash	Husk Temperature during combustion is 1000 °C	1	fig. 3	2750	
		Upper furnace, upper part 950 °C (increased air)	2	fig. 4	2600	
Feed-in reduced by 20% (hence O2 % increased), measures after 15 minuts.						
	Fly Ash	Upper Furnace 750 °C	3	fig. 5	1500	
		Upper Furnace 700 °C by increased excess air	4	fig. 6	1300	
	Bottom Ash	Upper Furnace 750 °C	3	fig. 7	1800	
		Upper Furnace 700 °C by increased excess air	4	fig. 8	1600	
	Fly Ash	Upper Furnace 750 °C, measures after 30 minutes	5	fig. 9	1375	
	Bottom Ash	Upper Furnace 700 °C	5	fig. 10	1950	
			6	fig. 11	1900	
Final adjustment						
	Powder ash	(Fly ash)	1	fig. 12	2500	
			2	fig. 13	4800	
			3	fig. 14	3750	
	Clinkers	(Bottom ash)	1	fig. 15	2100	
			2	fig. 16	1150	
			3	fig. 17	800	

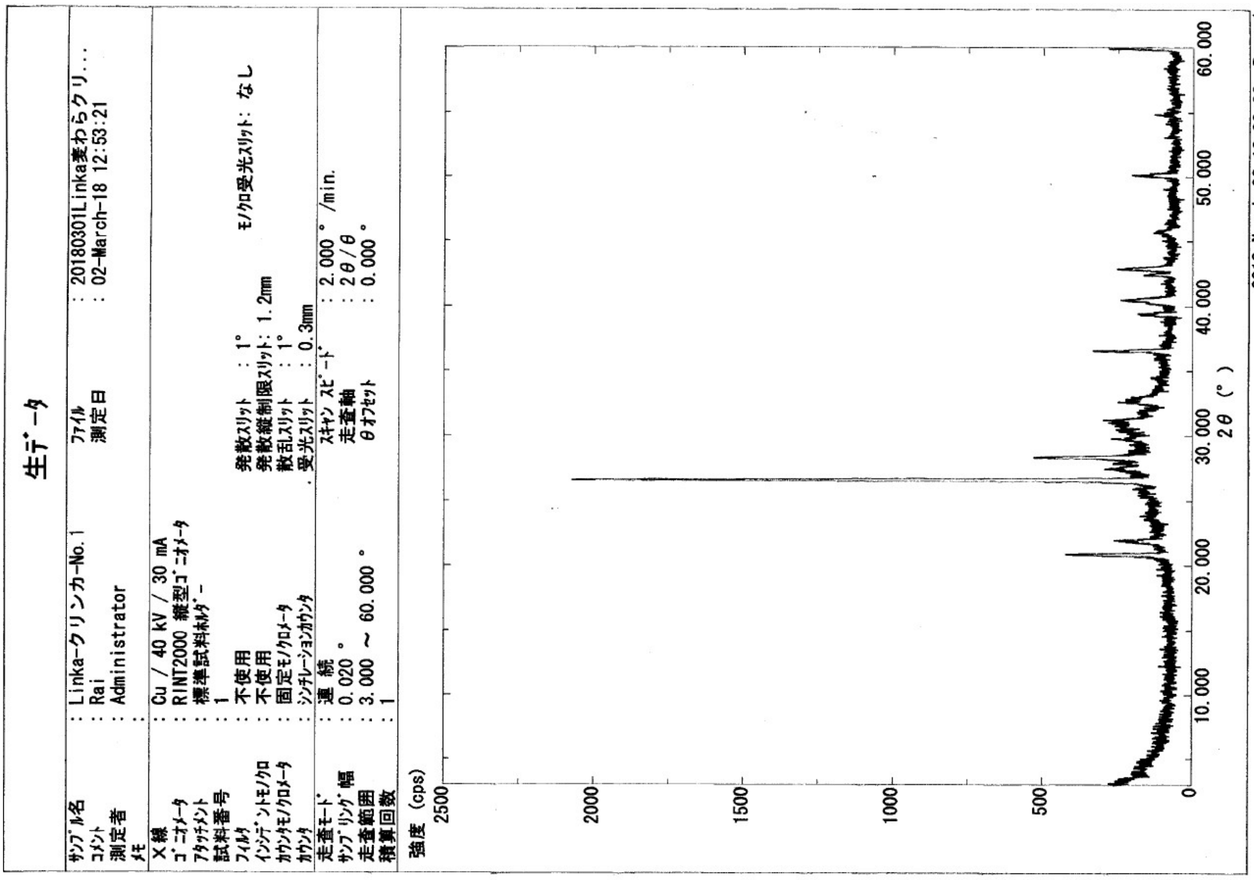


Fig. 15: Clinkers 1

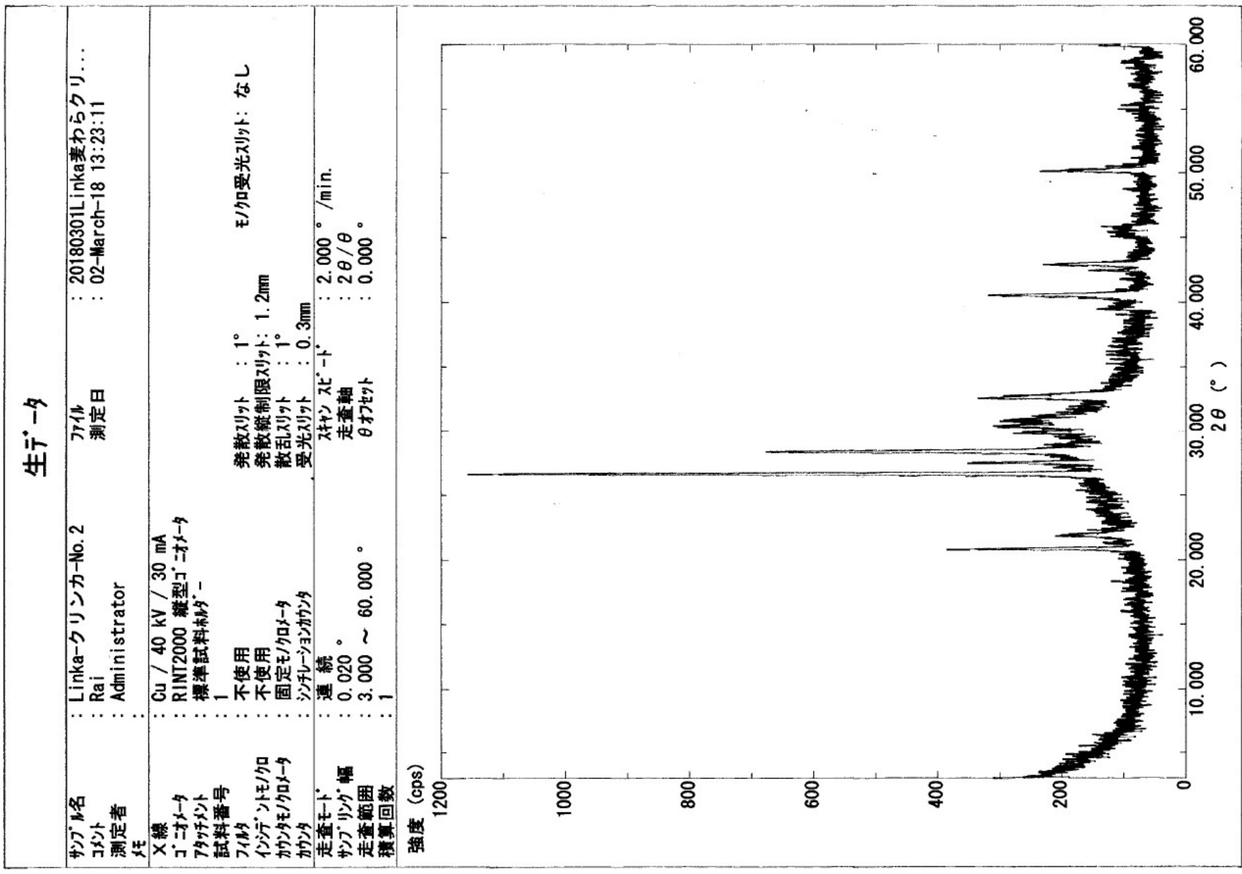


Fig. 16: Clinkers 2

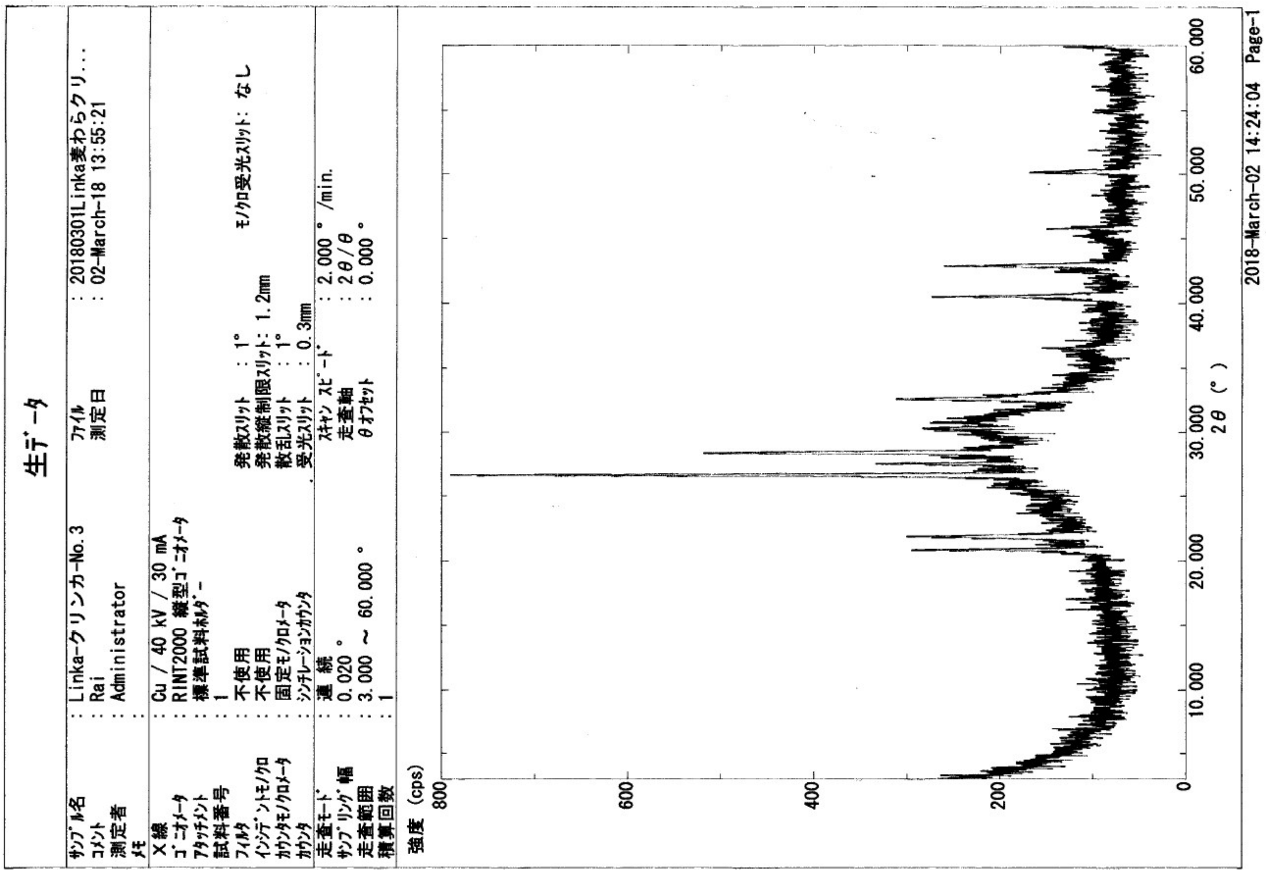


Fig. 17: Clinkers 3

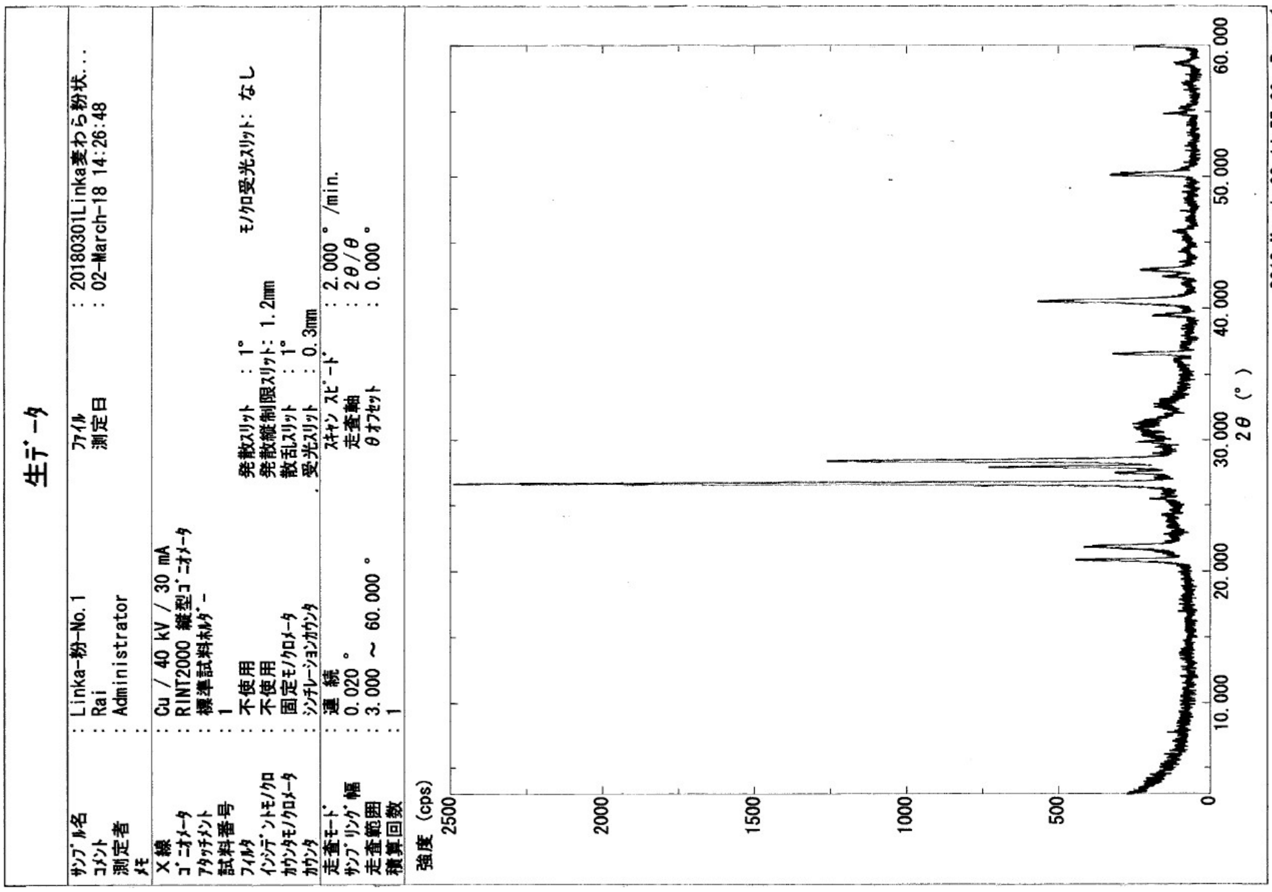


Fig. 12: Powder ash

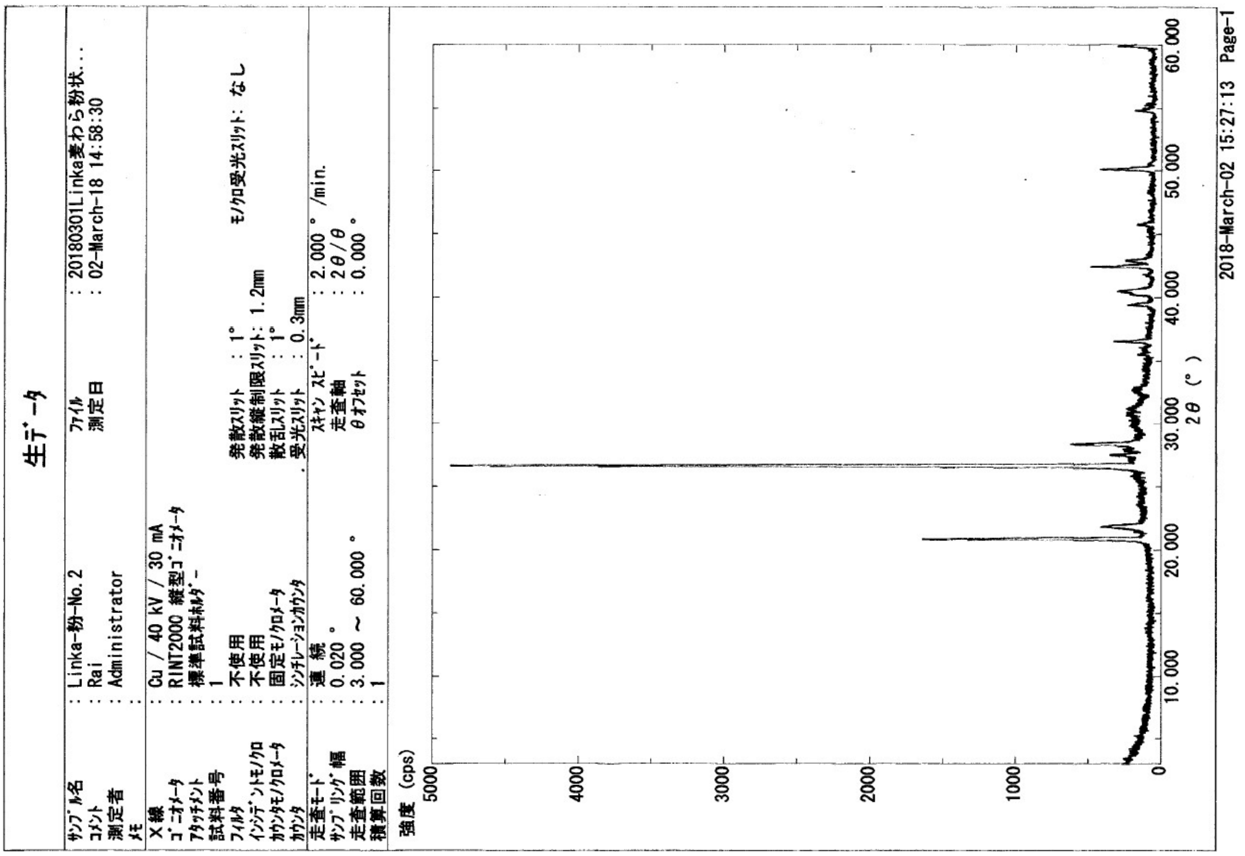


Fig. 13: Powder ash

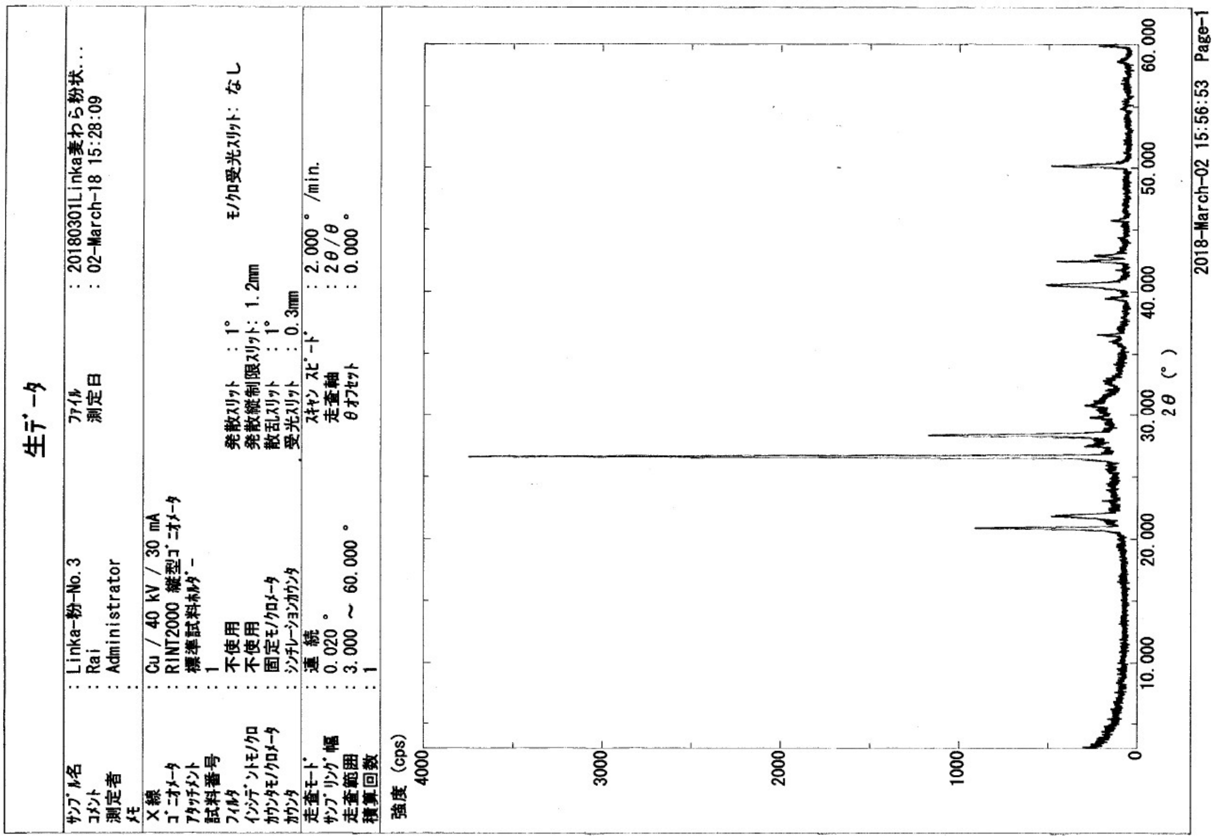


Fig. 14: Powder ash

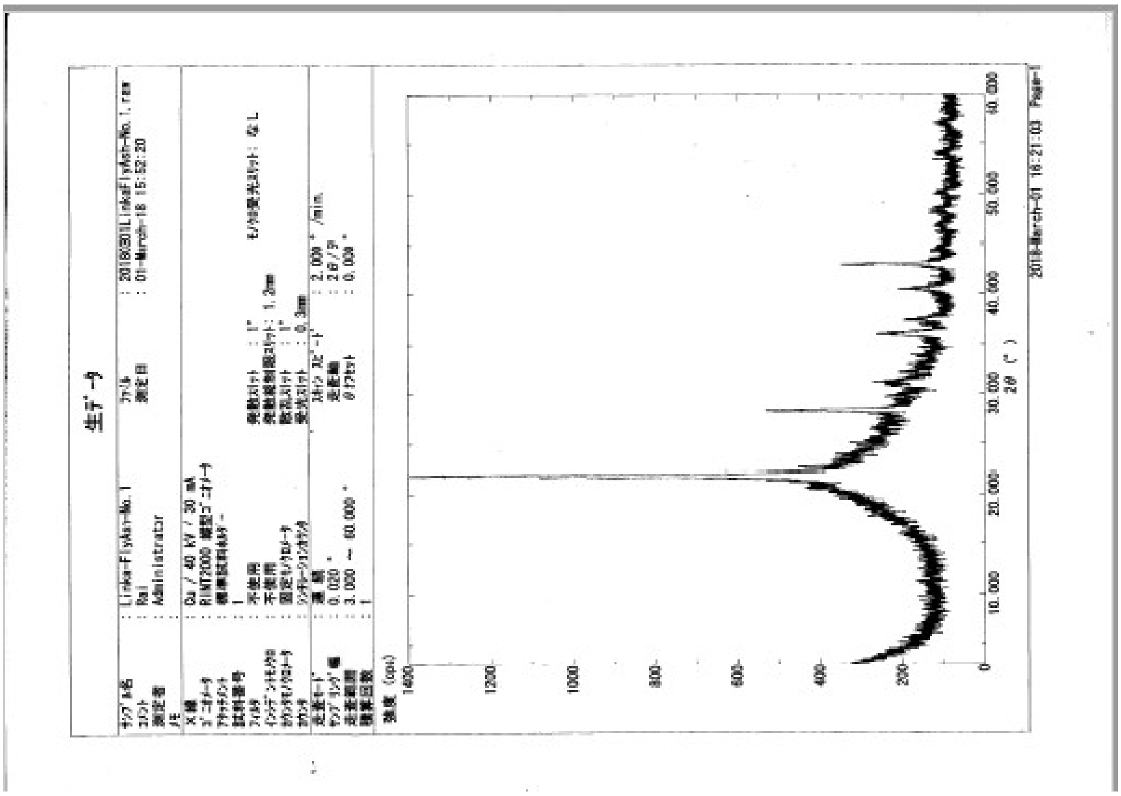


Figure 3: X-ray analysis result no 1 Fly ash – Ash temperature at grate 1000°C

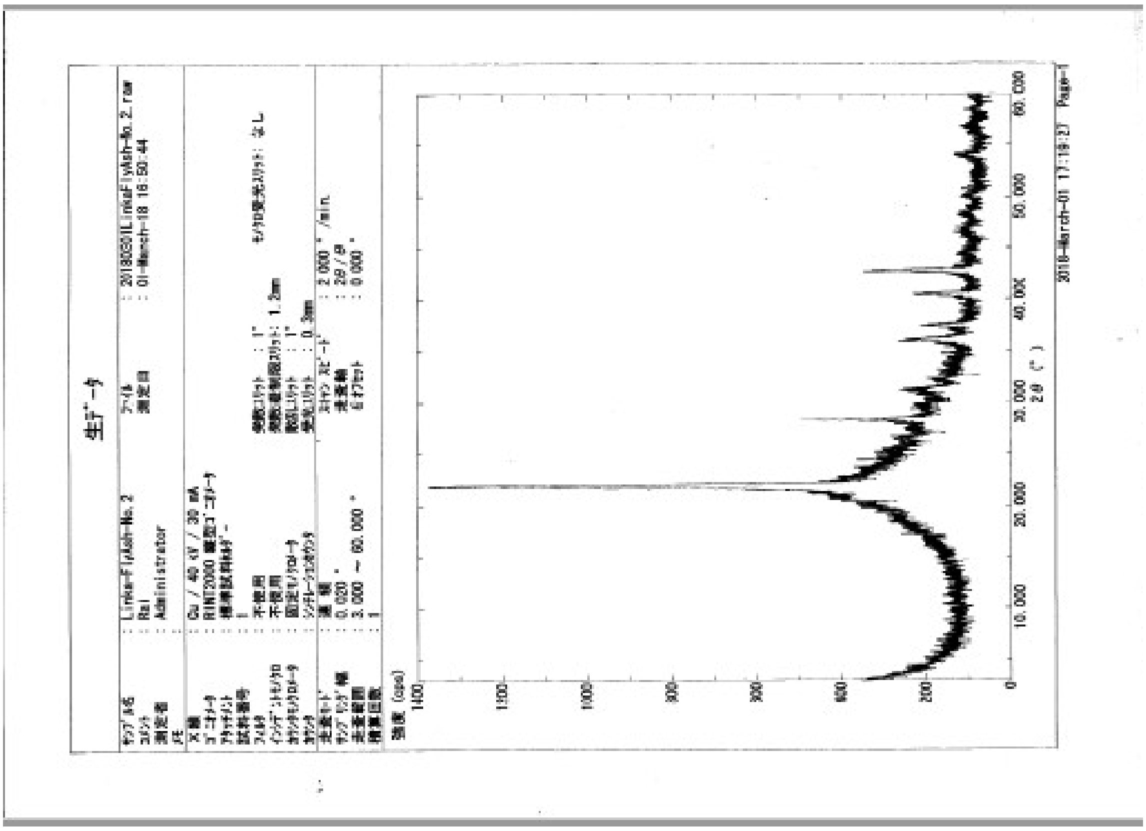


Figure 24: X-ray analysis result no 2, Fly ash – Ash temperature at grate 950 °C

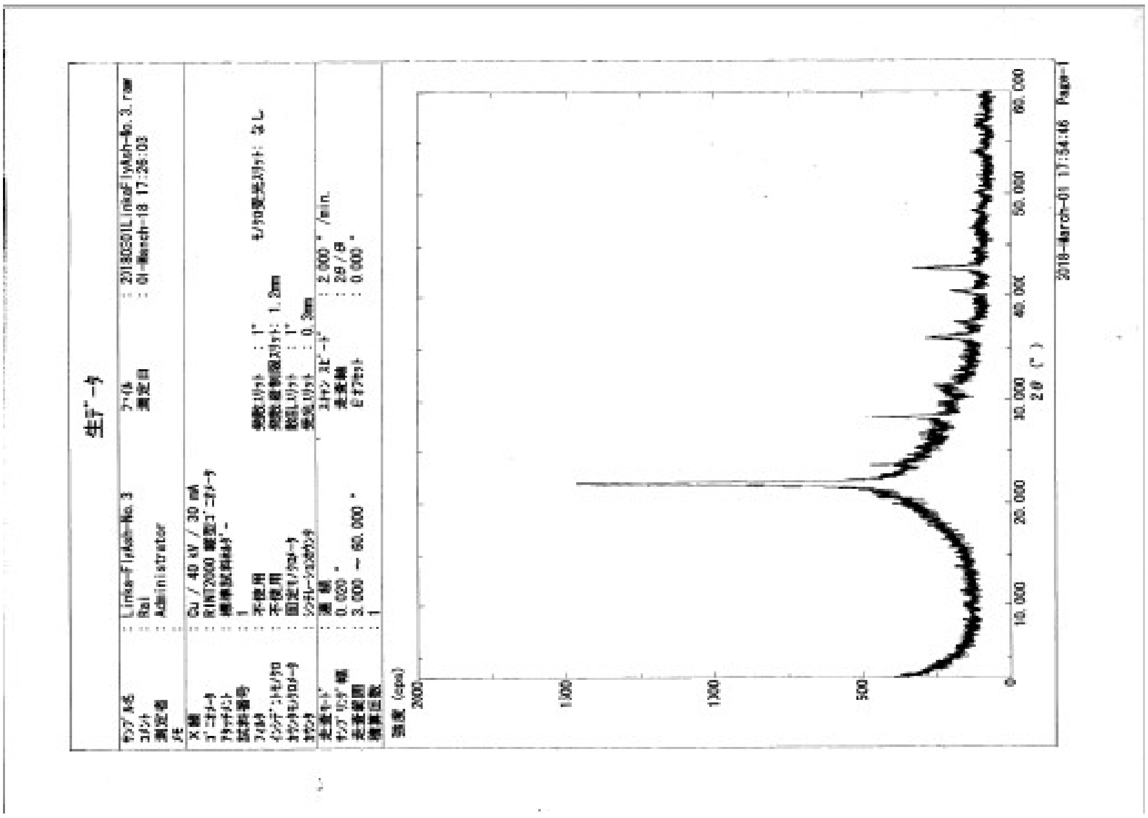


Figure 3 X-ray analysis results of Fly-ash no 3– Ash temperature at grate 750 °C

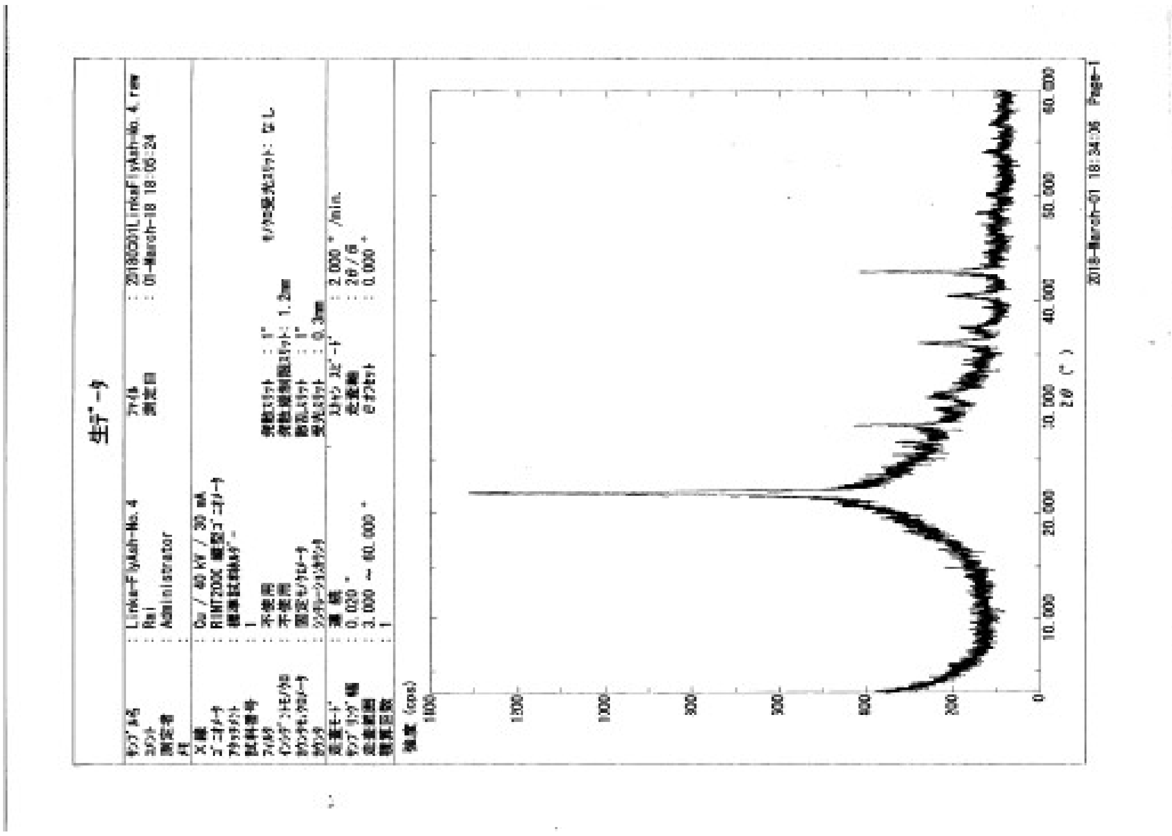


Figure 4: X-ray analysis results of Fly-ash no 4 – Ash temperature at grate 700 °C

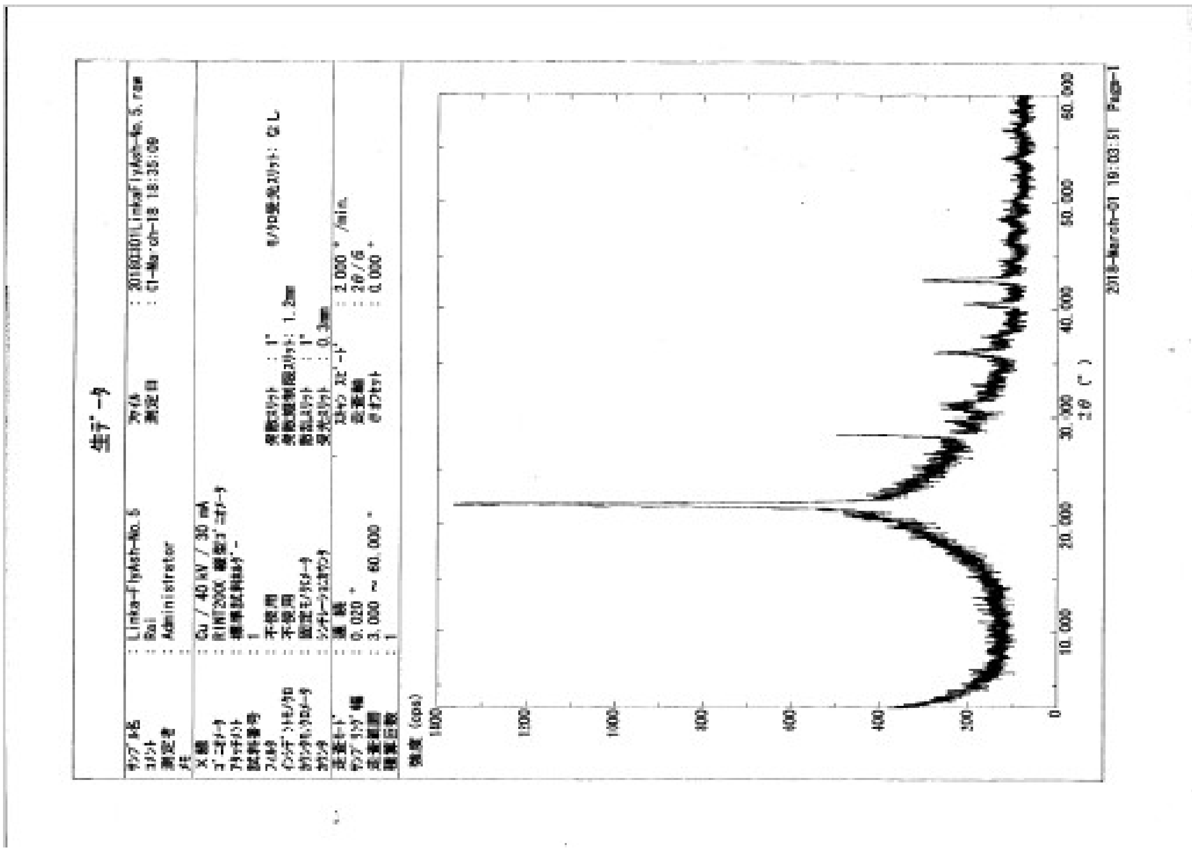


Figure 5: X-ray analysis of Flyash no. 5 – Ash temperature at grate 750 °C

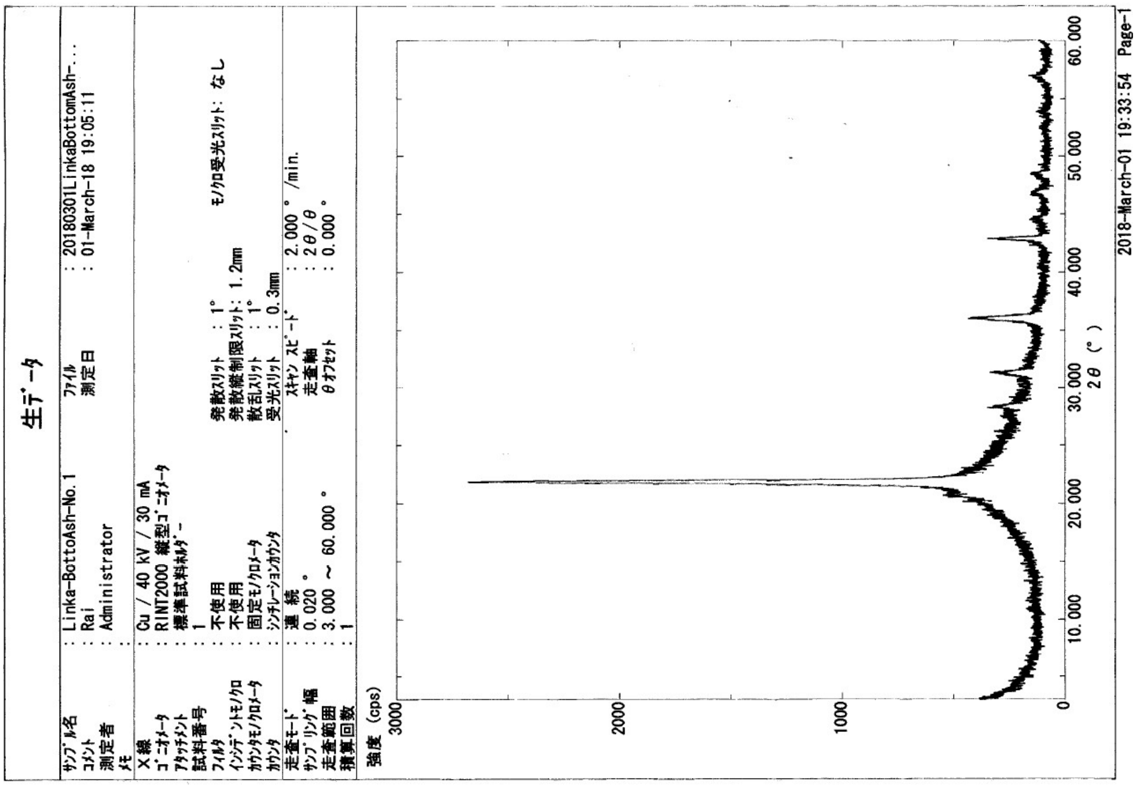


Figure 6: X-ray analysis of Bottom ash No 1 – Ash temperature 1000 °C

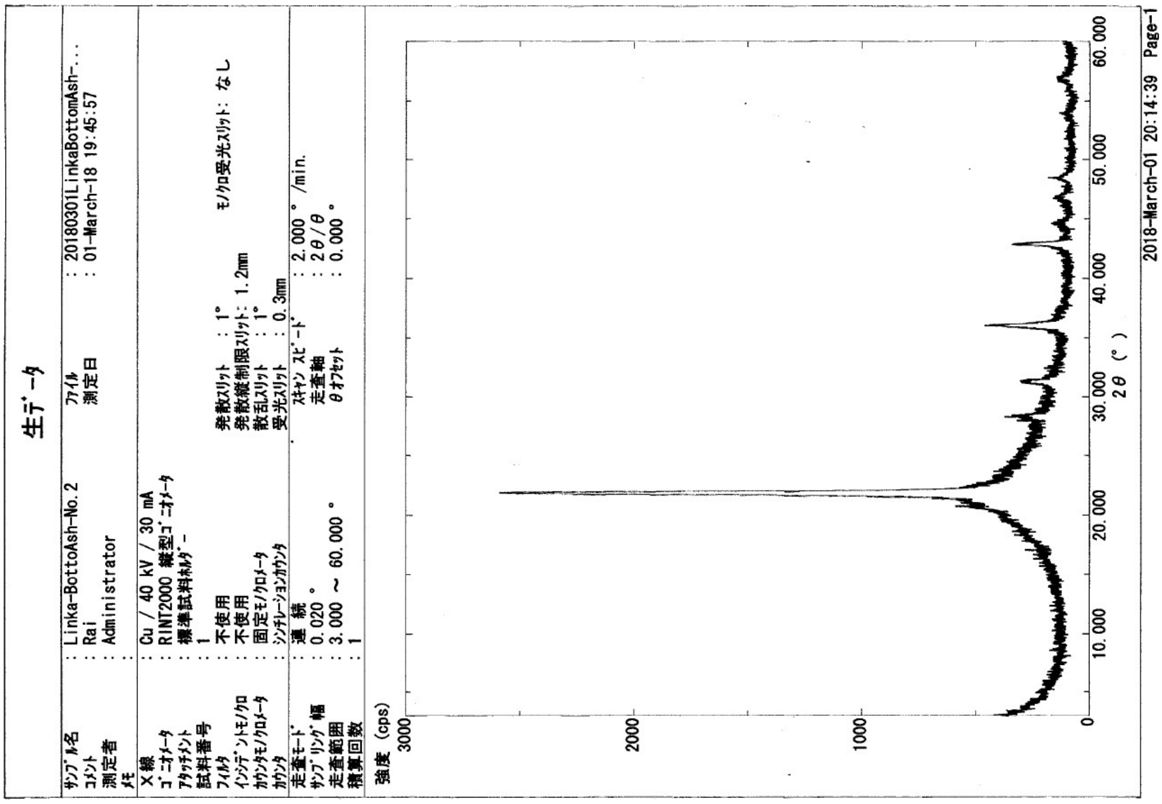


Figure 7: X-ray analysis of Bottom ash No 2 – Ash temperature 950 °C

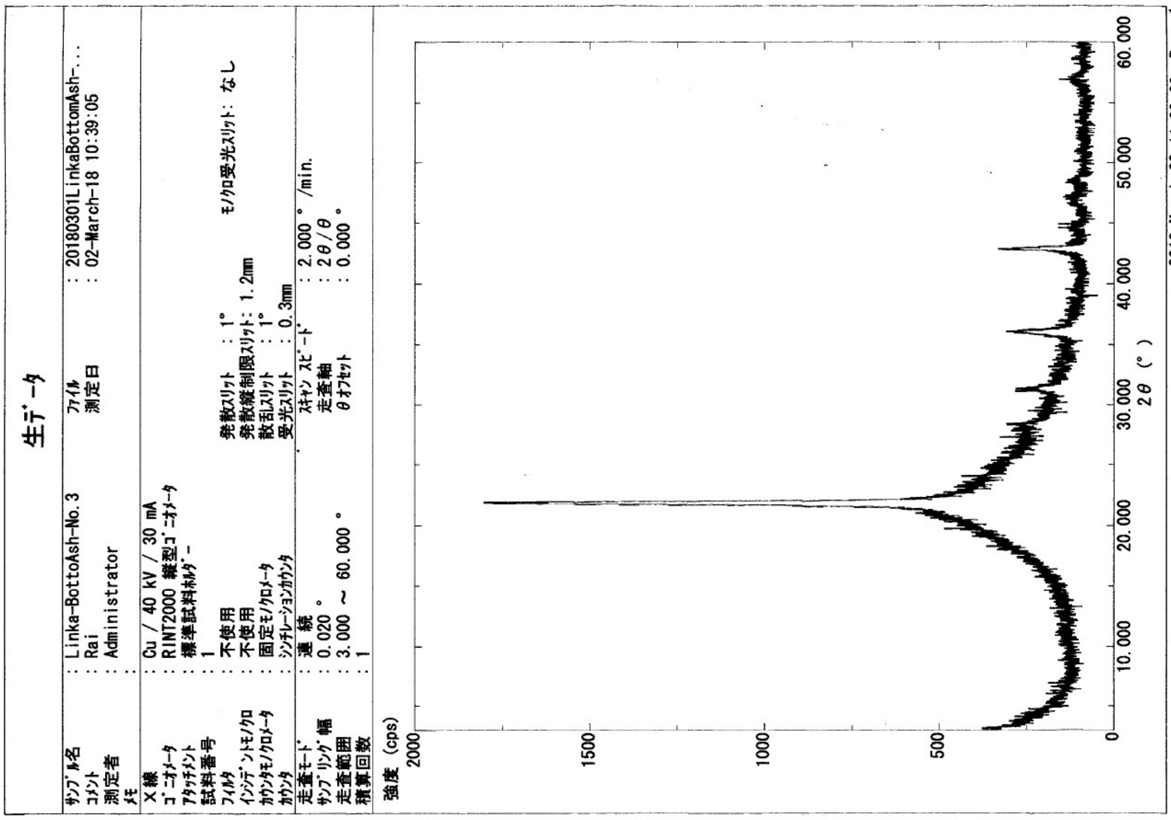


Figure 8: X-ray analysis of Bottom ash No 3 – Ash temperature 750 °C

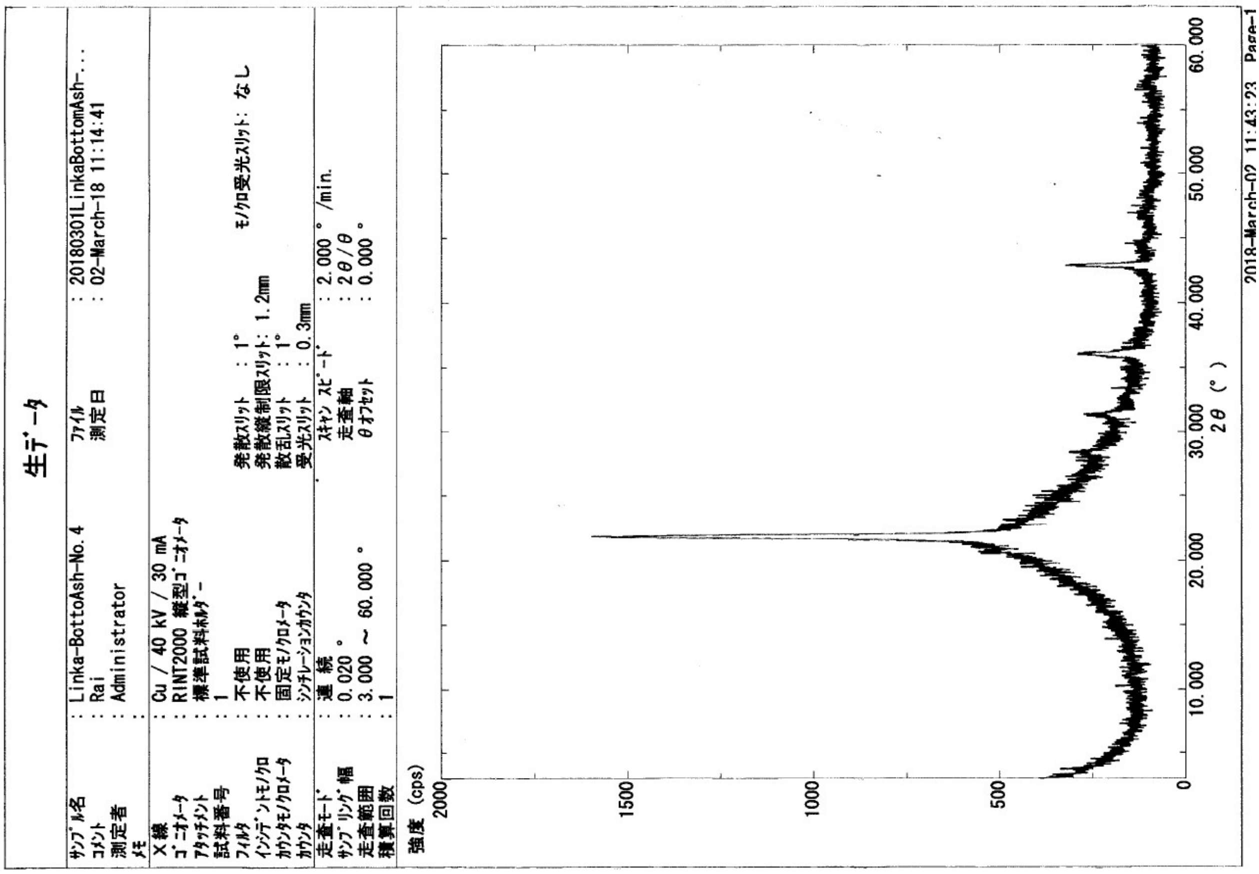


Figure 9: X-ray analysis of Bottom ash No 4 – Ash temperature 700 °C

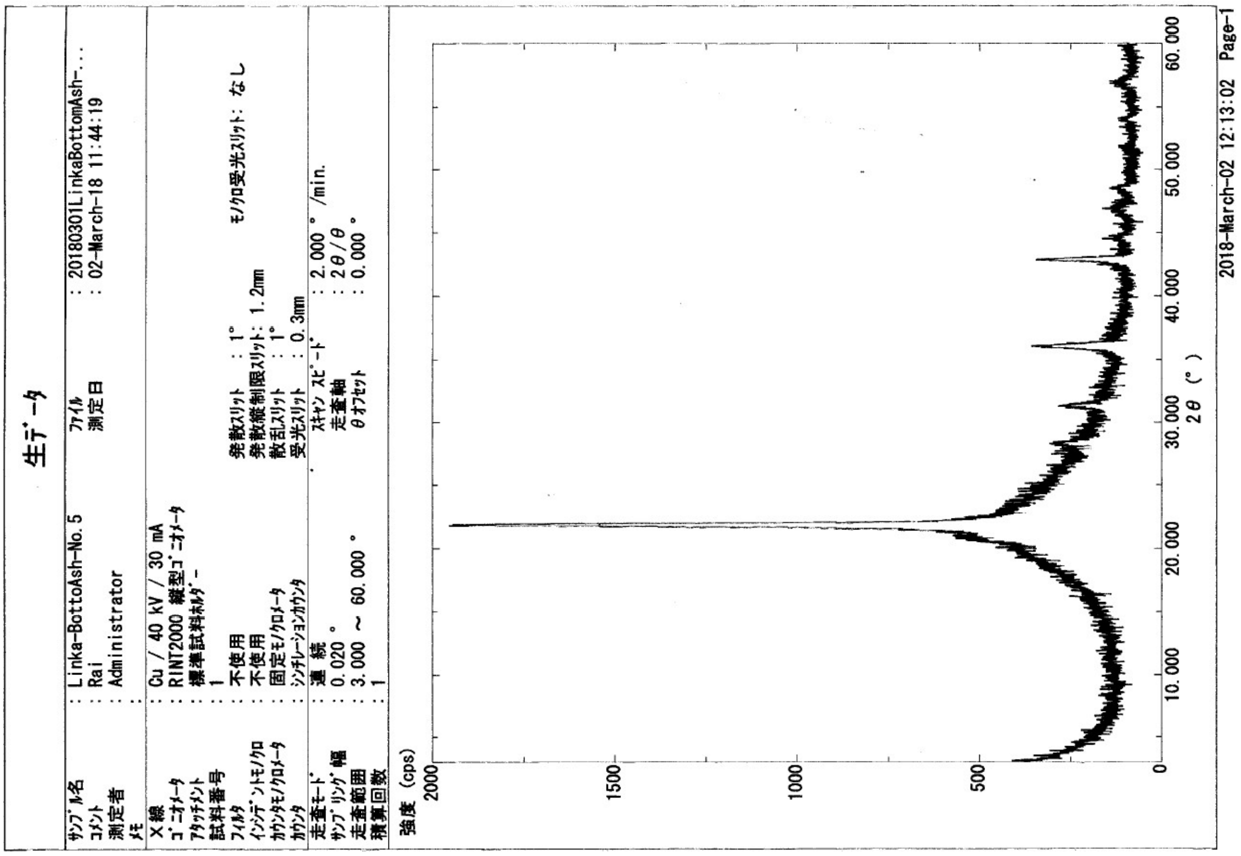


Figure 10: X-ray analysis of Bottom ash No 5 – Ash temperature 700 °C

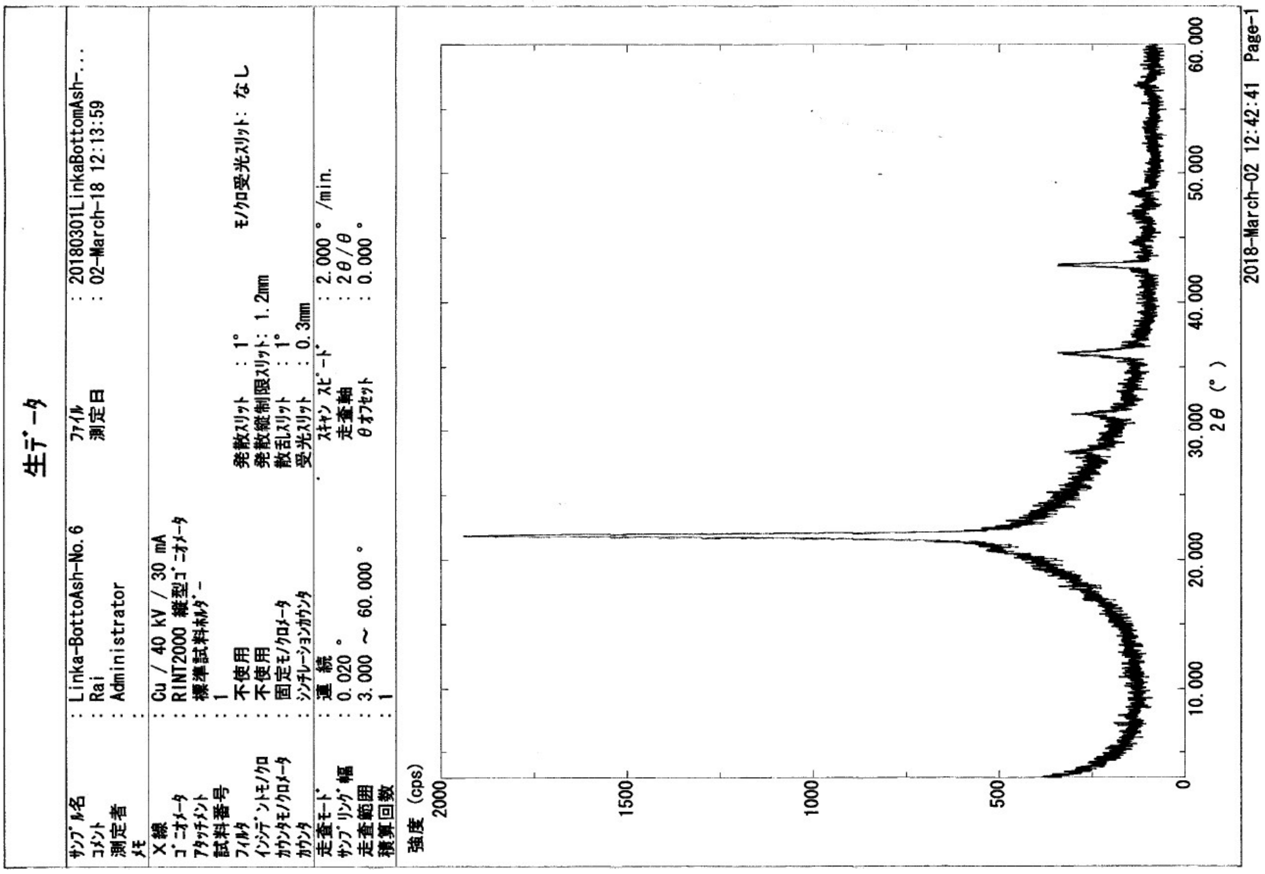


Figure 11: X-ray analysis of Bottom ash No 6

Appendix 4. Preliminary Comb. of Rice Husk - Jan. 31st 2018 - TwinHeat A/S

Report prepared by Jens Birch Jensen, PlanEnergi.

TEST REPORT

Incineration of 'rice husk' 31.01.2018 at TwinHeat

TEST DATA

- TwinHeat 80 kW (Nominal heat power on dry wood chips) boiler with tube burner
- The boiler has been installed with automatic ash ejection system and a cleaner rod has been installed into the combustion tube to be able to move the ash.
- Test running from 09:30 – 14
- Boiler was started and running on Rice Husk from the morning and at operating condition at the start of the test

- An average of 18 kW is produced
  Flue gas temperatures not measured
- Combustion efficiency was not measured

TEST RESULTS

During the test ash samples were taken from the ash tray and from diffent places in the combustion pipe ie. at different points of combustion time.

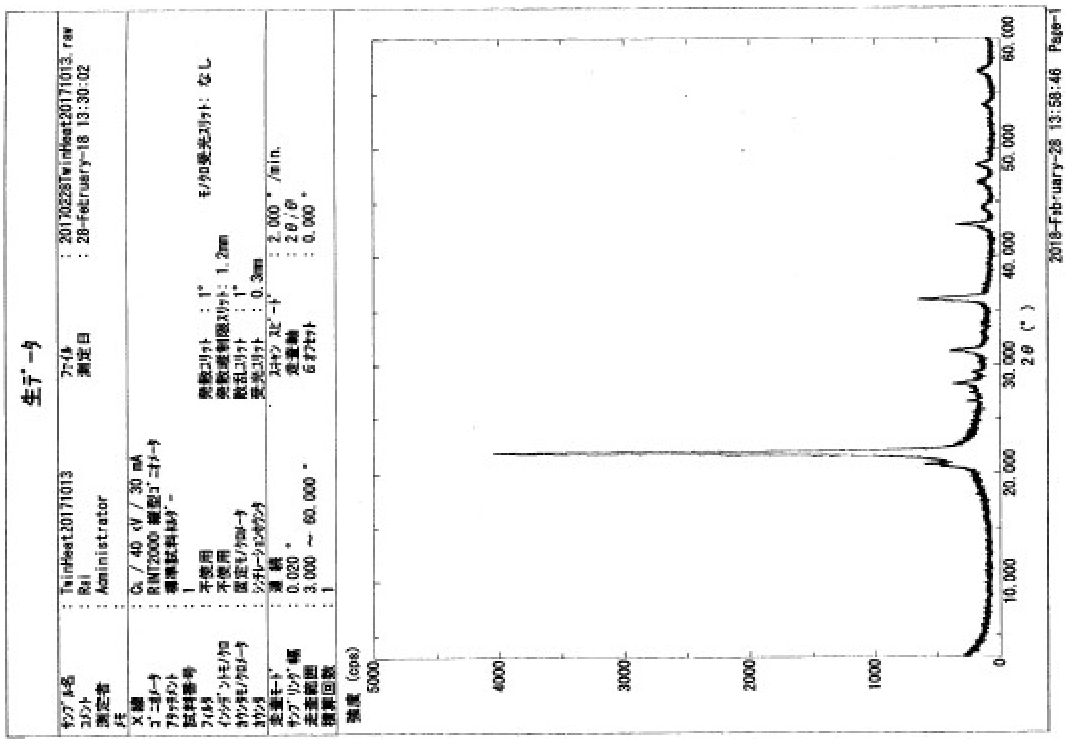
Dr. Rai has analyzed ash samples from TwinHeat combustion tests samples by X-ray and NC analyzer.
The analysis show a relative high degree of crysatllization in all samples.

Ash analysis performed by Dr. Rai, University of Akita

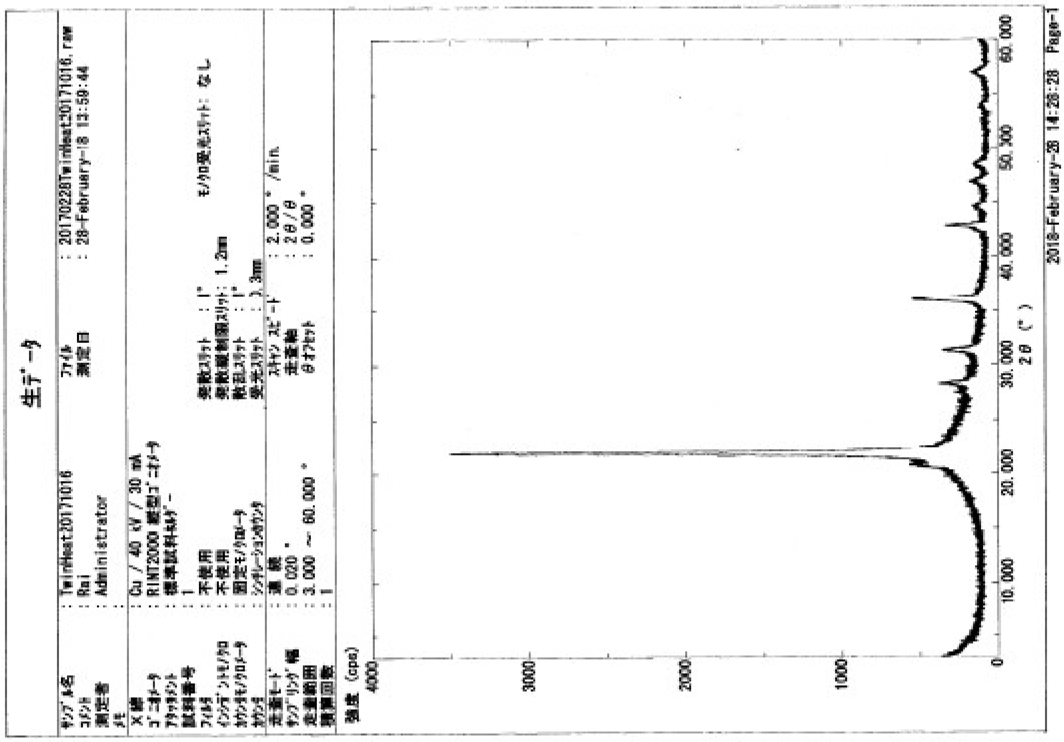
Table 1 List of ash samples and analysis result.

Danish combustion ash analysis						
Visit to regional heat supply facility						
Twin Heat					Crystallization	
					CPS	%
	2018-31-01	Initial condition	1	fig. 8	2750	
	2018-31-01	Initial condition	2	fig. 9	3800	
	2018-31-01	Initial condition	3	fig. 10	4000	
	2018-31-01	Initial condition - extracted from the combustion tube	4	fig. 11	3000	
	2018-31-01	Initial condition - extracted from the combustion tube	5	fig. 12	3000	
	2018-31-01	Initial condition - extracted from the combustion tube	6	fig. 13	2400	
	2018-31-01	Increased fuel input, and air volume	Fast1	fig. 14	3700	
	2018-31-01	Increased fuel input, and air volume	Fast2	fig. 15	3400	
	2018-31-01	Increased fuel input, and air volume	Fast3	fig. 16	3400	
	13-10-2017	Preliminary test, ash samples without automatic ash removal		fig. 1	4000	
	16-10-2017			fig. 2	3500	
	23-10-2017			fig. 3	2500	
	24-10-2017			fig. 4	4000	
	25-10-2017			fig. 5	4400	
	30-10-2017			fig. 6	3700	
	31-10-2017			fig. 7	4300	
It is assumed that test result of 6000 cps is 100% crystallization - 1100 cps is 15%						
Accept limit is supposed to be <500 cps						

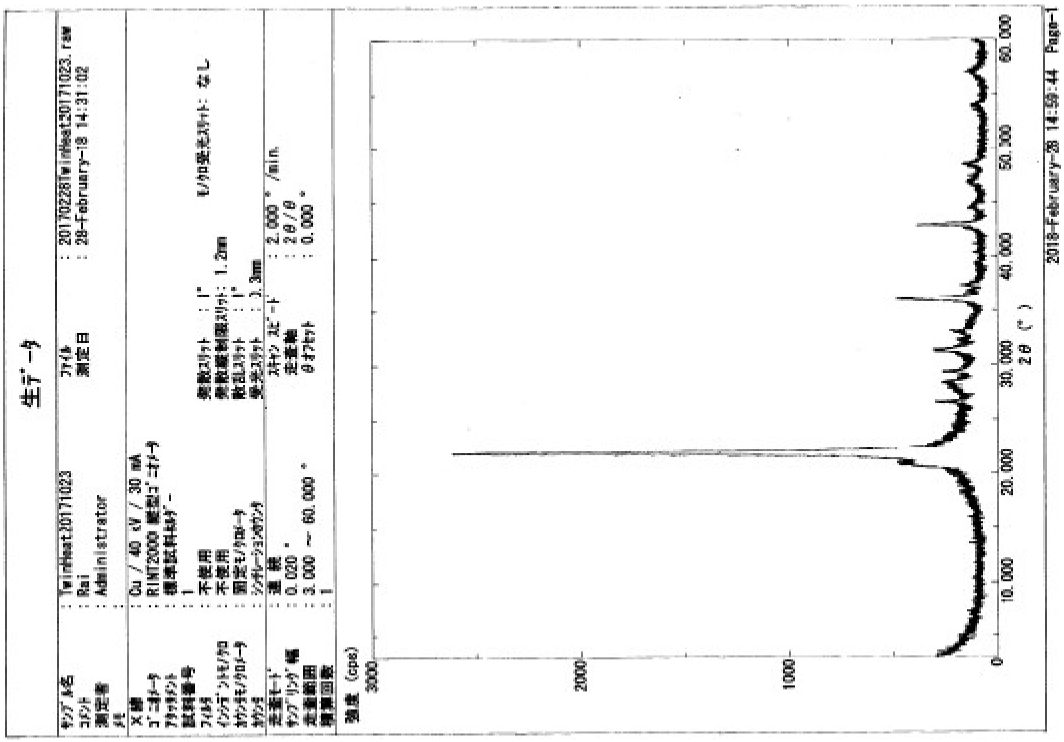
A. Analysis from preliminary test in October 2017



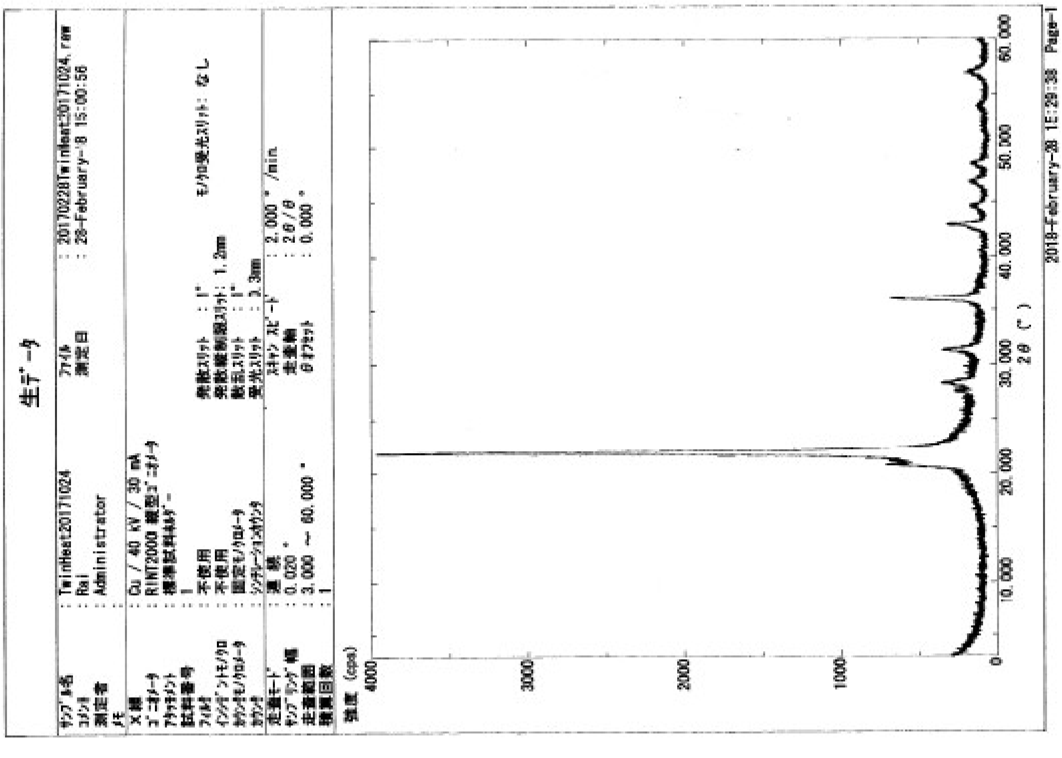
Figur 3: Ash sample 2017-10-13; 4000 cps



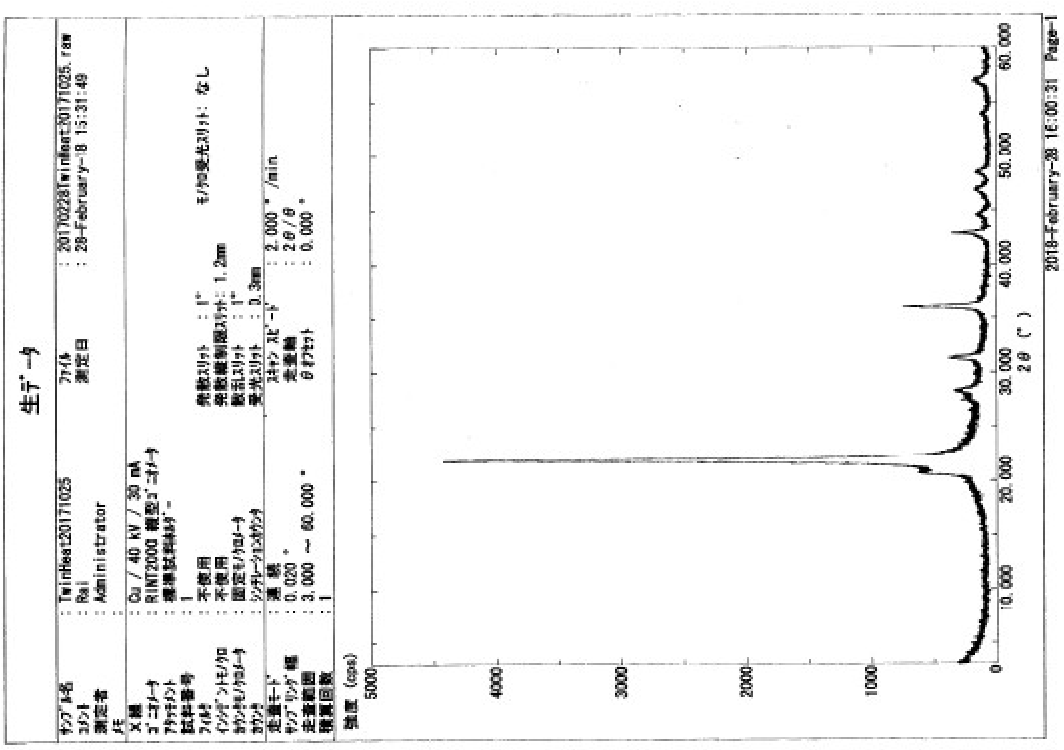
Figur 4: Ash 2017-10-16 : 3500 cps



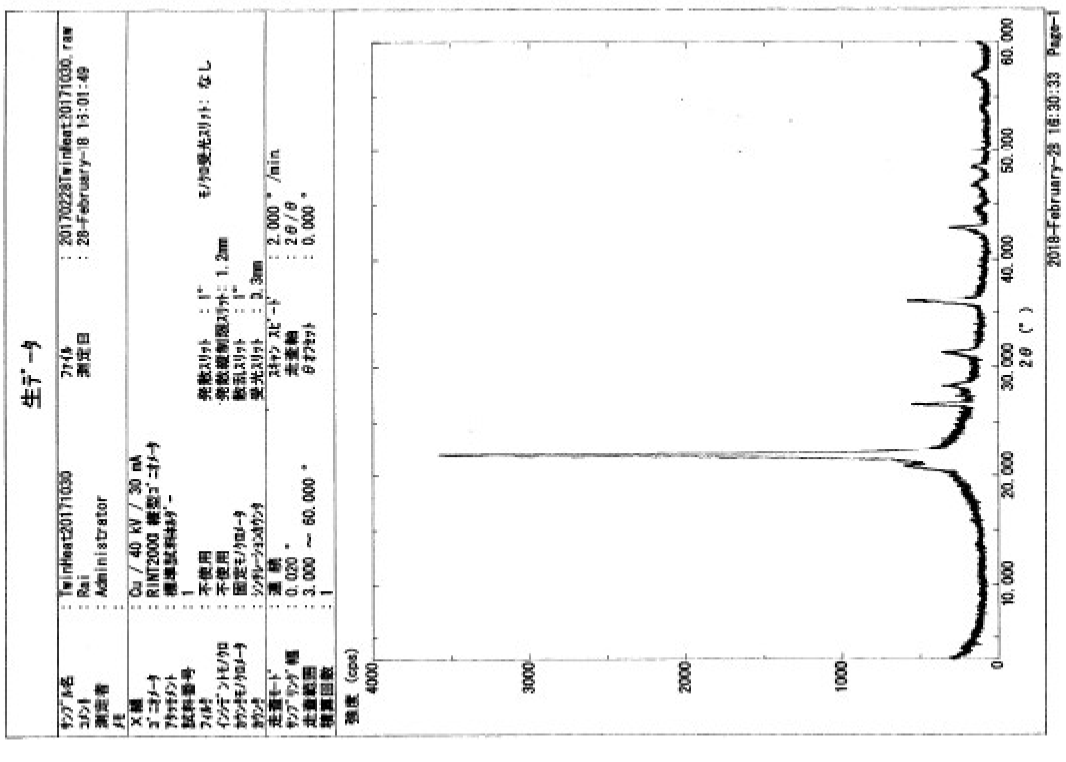
Figur 5: Ash sample 2017-10-23; 2500 CPS



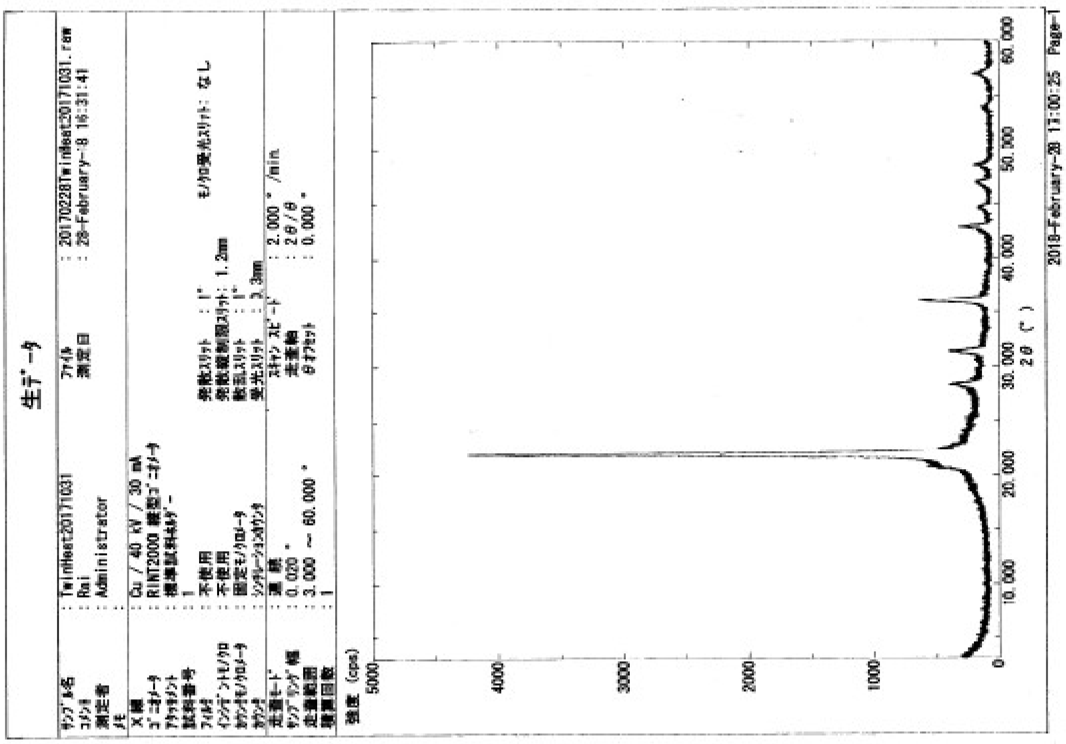
Figur 6: Ash sample 2017-10-24; 4000 cps



Figur 7: Ash sample 2017-10-25; 4400 Cps

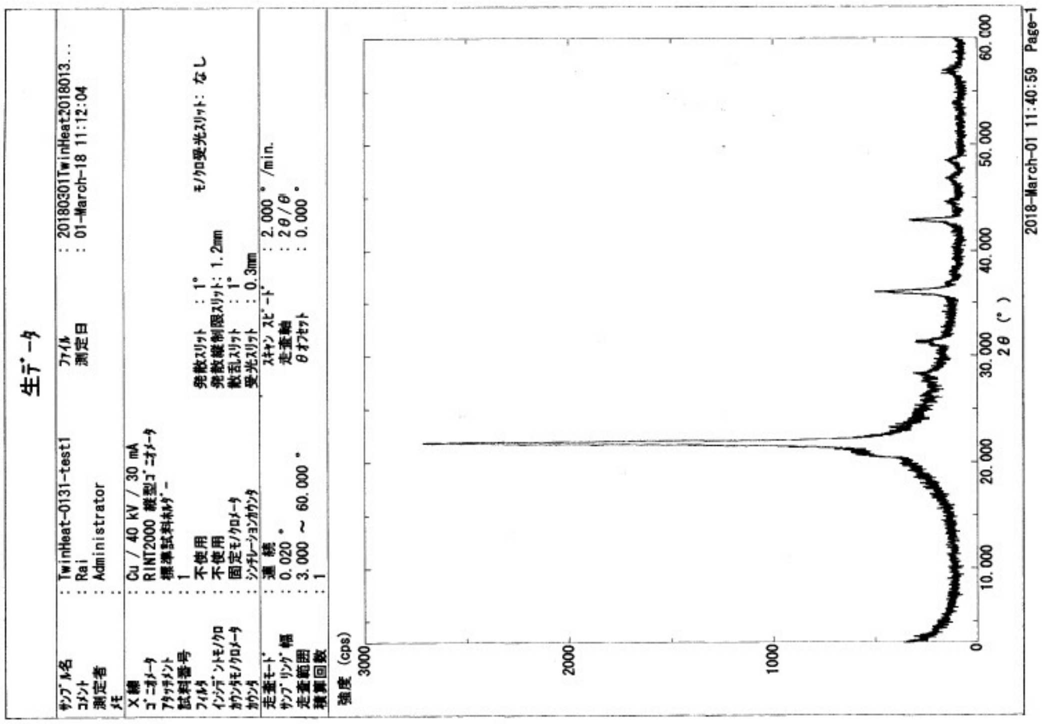


Figur 8: Ash sample 2017-10-30; 3700 cps

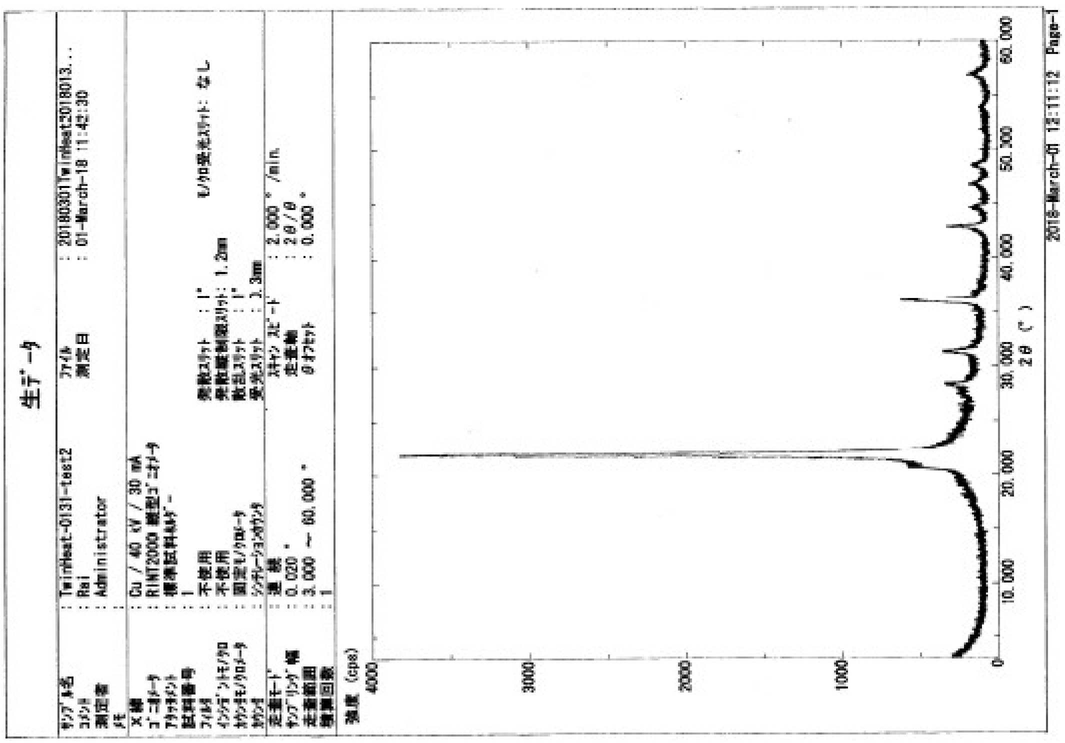


Figur 9: Ash sample 2017-10-31; 4300 cps

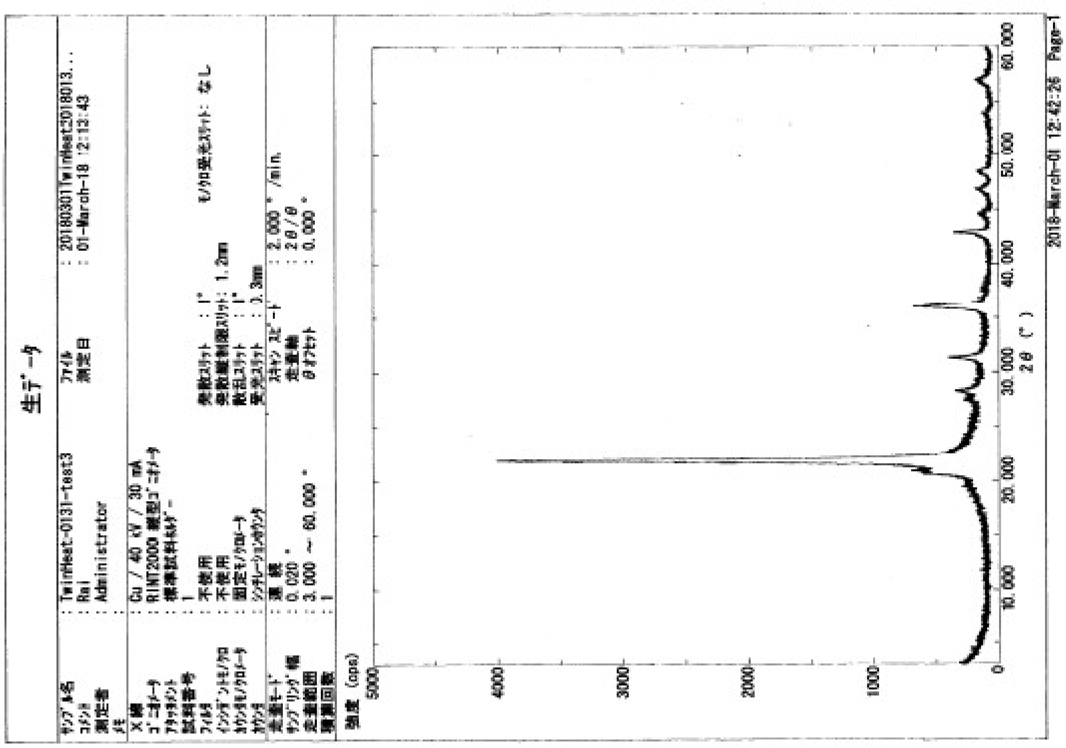
B. Analysis from preliminary test in January 2018



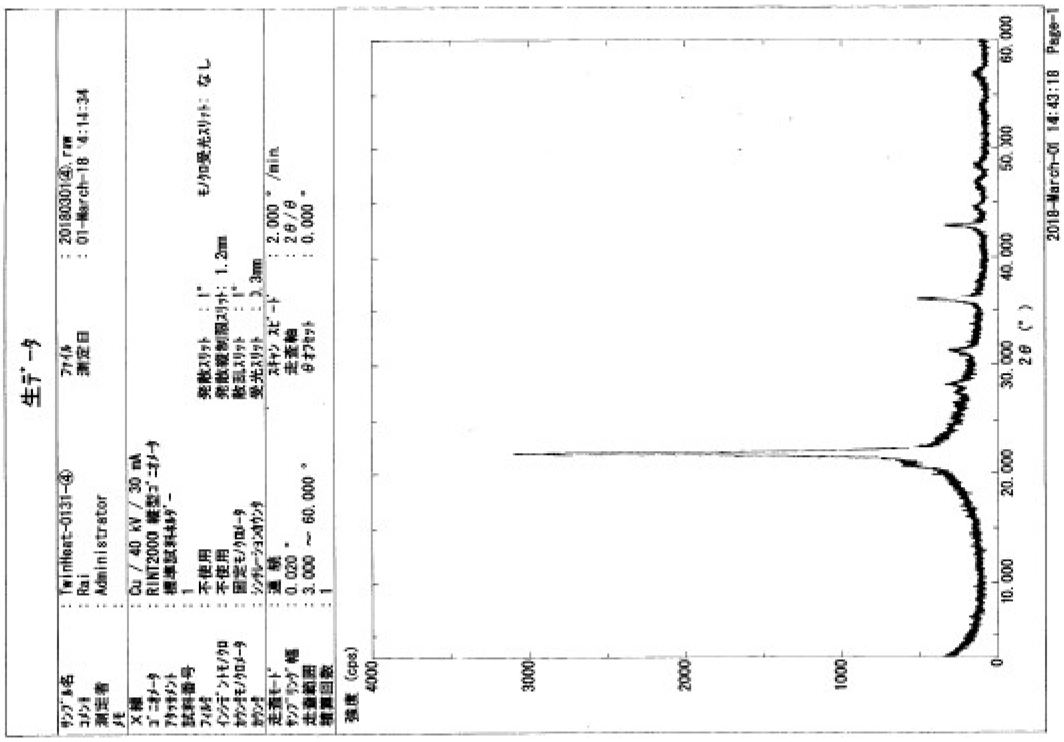
Figur 10: Ash sample 2018-01-31, test-1; 2750 cps



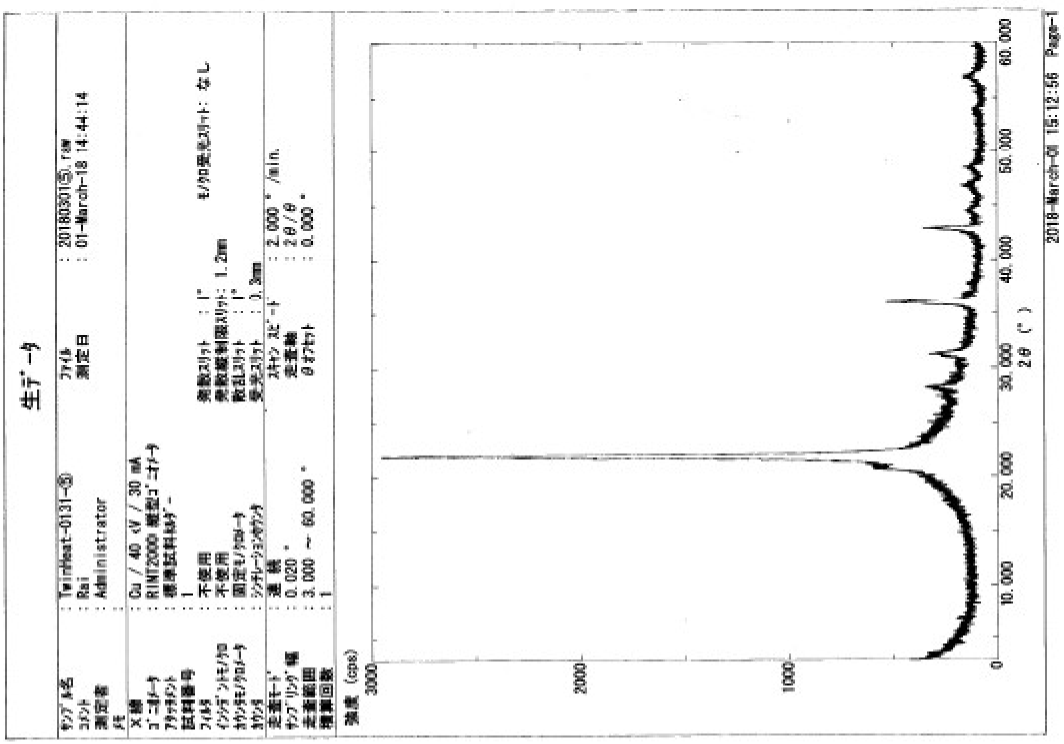
Figur 11: Ash Sample 2018-01-31, Test 2; 3800 cps



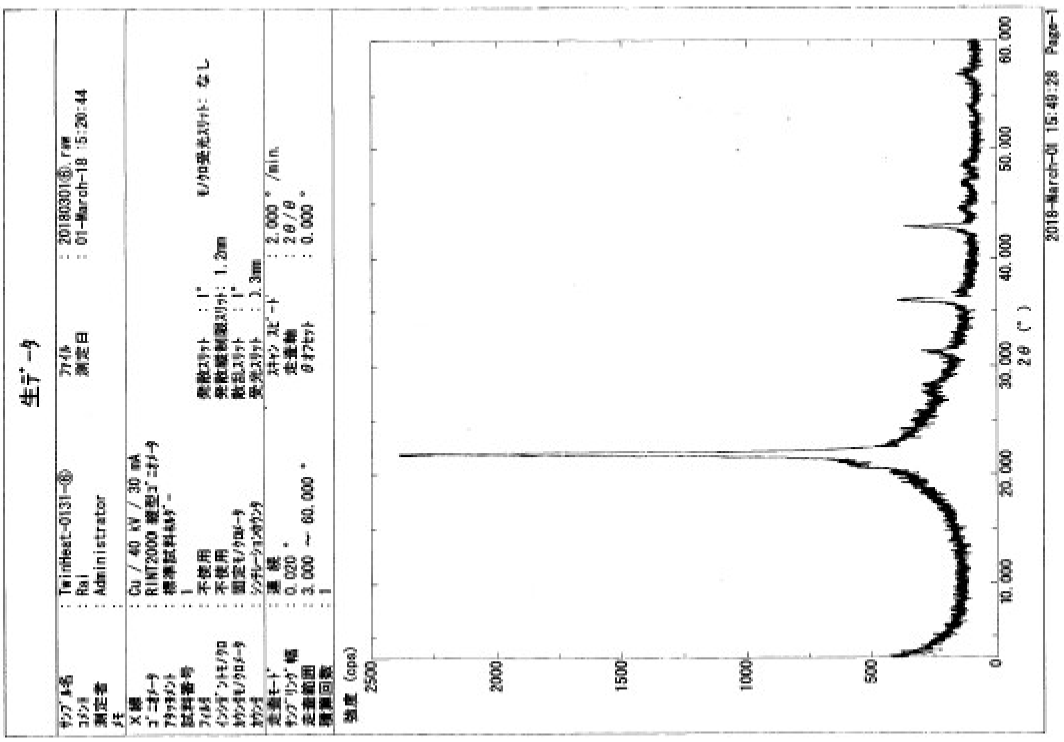
Figur 12: Ash sample 2018-01-31; test 3; 4000 cps



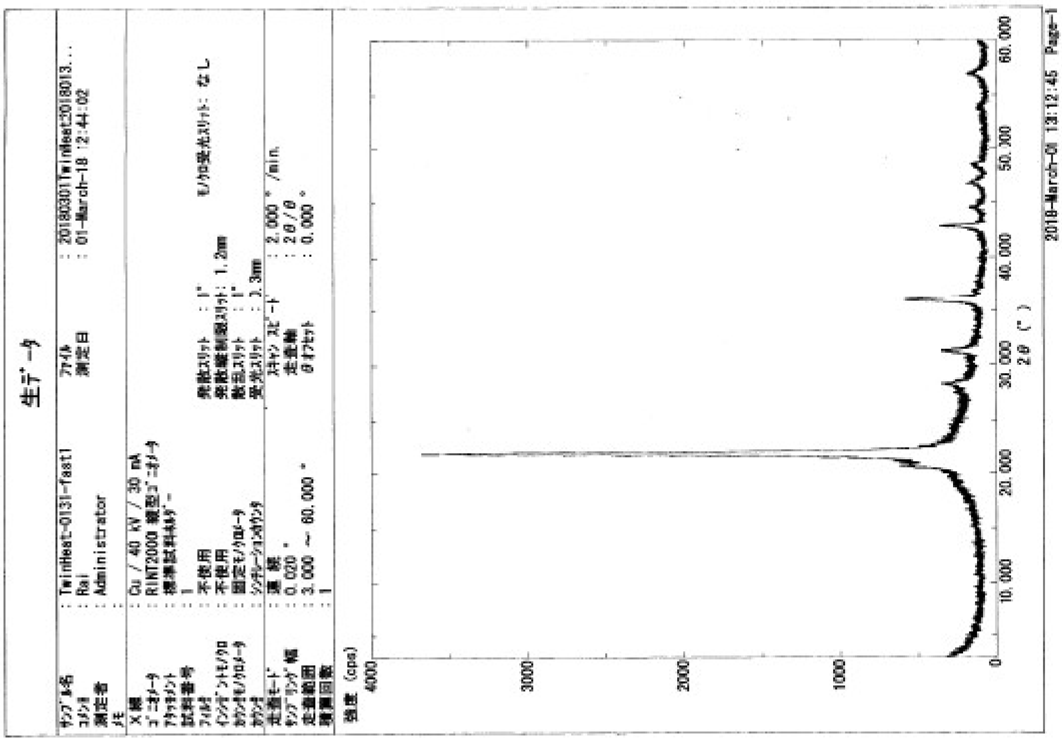
Figur 13: Ash Sample 2018-01-31 test 4; 3000 cps



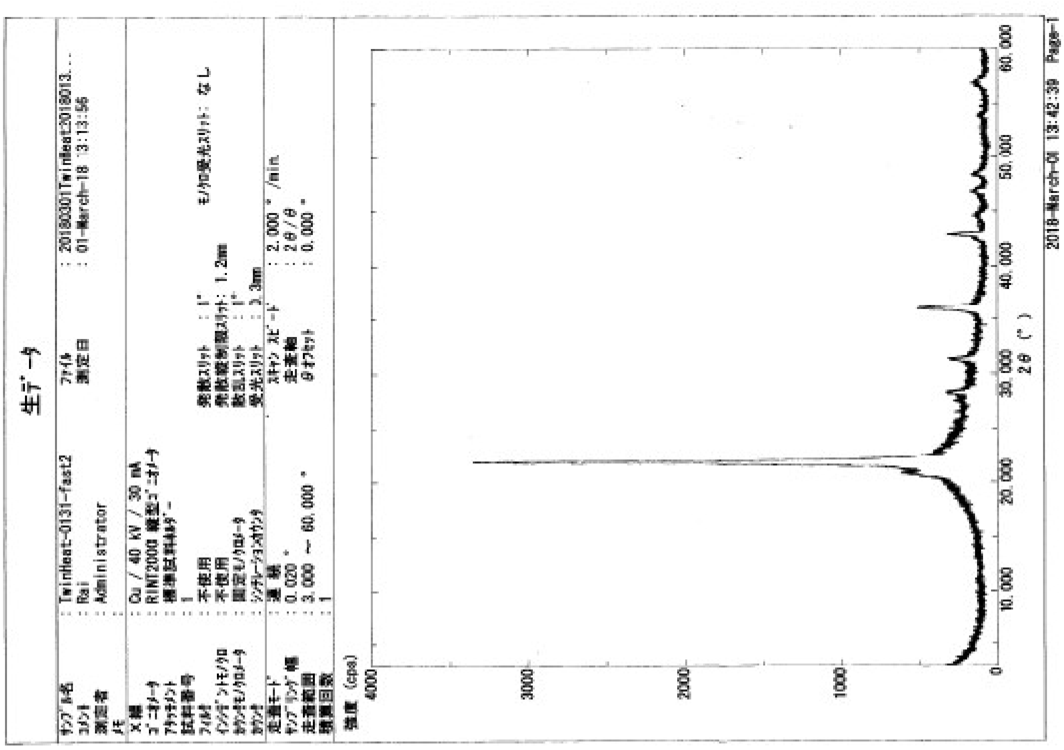
Figur 14: Ash sample 2018-01-31, test 5, 3000 cps



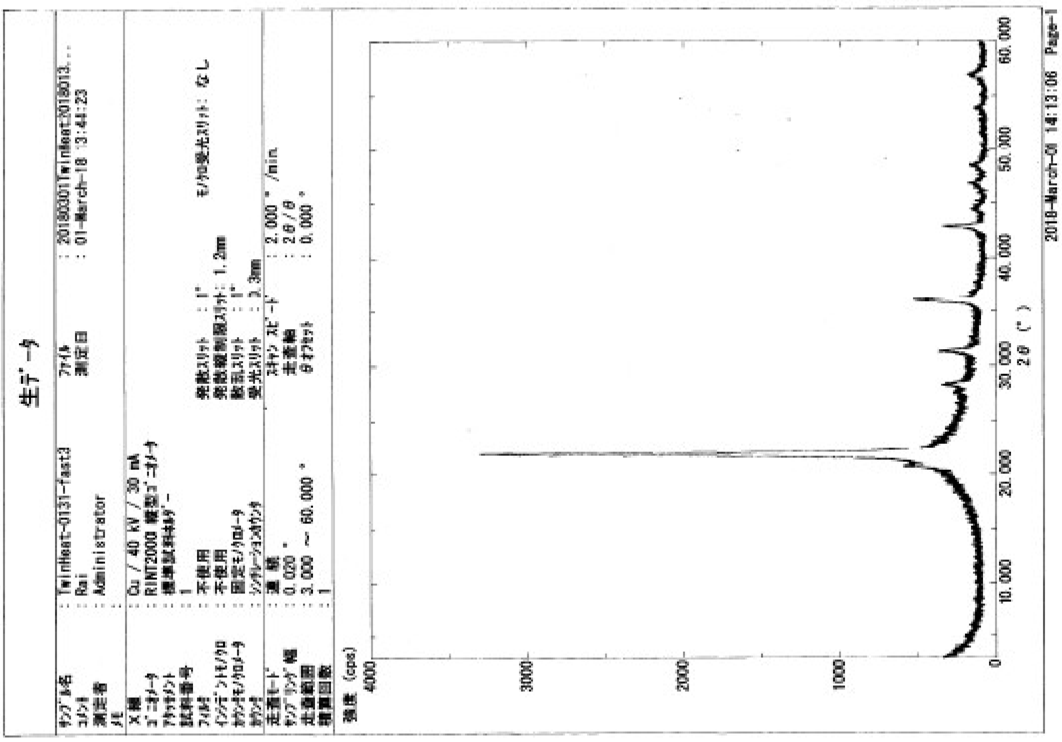
Figur 15: Ash sample 2018-01-31, test 6; 2400 cps



Figur 16: Ash sample 2018-01-31, test "fast1"; 3700 cps



Figur 17: Ash sample 2018-01-31, Test "fast 2", 3400 cps



Figur 18: Test sample 2018-01-31, Test "fast3"; 3400 cps

Appendix 5. Second test round, Linka - Sept. and Dec. 2018

Conclusion on tests and ash analysis

From the test result is may be concluded that the theory of the relation between retention time and crystallization is correct. If the combustion zone is very short the crystallization is reduced. But at the same time the efficiency will be reduced due to high carbon content in the ash (unburned fuel).

If the combustion temperature is kept below 700 °C it is very likely that crystallization may be avoided.

A. Combustion of Rice Husk sept. 9th at Linka Energy A/S

Report prepared by Jens Birch Jensen, PlanEnergi.

TEST REPORT

Grate moving equipment changed from electric to hydraulic to increase speed of grate movement hereby reducing ash time in grate

- TEST DATA
  Linka 400 kW (Nominal heat power on dry wood chips) boiler with moving grate

- The boiler has 3 primary combustion zone which may be individual adjusted
  The grate movement speed may be adjusted. Due to the amount of ash compared to woodchips the grate is running at max. speed.

- Boiler Construction changes.
  1) The electrical driven grate movement system is exchanged to hydraulic system to enhance the speed of the grate movements.
  Each movement is 20 cm, performed in 20 sek. (Forward and return). Lenght of grate is 183 cm. Fuel residence time on the grate is estimated to 3-5 minutes.
  2) the boiler is equipped with flue gas return to primary air.
  It was experienced that the O2-content was to small to ignite the rice husk and the flue gas return was closed.

- Test running from 09:30 – 16

- Boiler was started and running on Rice Husk from the morning and at operating condition at the start of the test

- An average of 200 kW is produced, boiler temperature T_f / T_r = 90/70 °C.
  Flue gas temperatures measured to 150-165 °C

TEST RESULTS

9:30 to 10:00
Visual observations: The combustion looks very fine – good ignition at top of grate and equal combustion throughout the grate (see photo #1)

Load approx.	200 kW
O2 %	7-9 %
CO	200 ppm (50-400 ppm)
NOx	170 ppm

At 10:00 a new sack of rice husk was filled in and it will not ignite (see photo #2 and #3).
The rice husk ignites at the last part of the grate and burns quite well.
Ash sample # 1: Short combustion (difficult ignition) from bottom of grate.

At 13:15 – Grate is cleaned up and boiler restarted on a new sack of Rice Husk.
Combustion is very fine on all of grate.
Ash sample #2 taken at 14:45 (#2A from last grate and #2B from ash bin)

At 14:55 – a new sack of rice husk filled in.
Again this rice husk will not ignite before last step of the grate i.e. very short time of combustion.
Ash sample # 3 taken at 15:15. (#3A from last grate and #3B from ash bin)

Conclusive remarks on this test.

It was not possible to perform a reasonable test because the rice husk seems different from one package to another.

It was not possible to observe any difference of the husks either in structure or humidity.

Because the continuous combustion was short it was not possible to measure combustion temperatures.

Experiences obtained by the test

Both samples of rice husks may be possible to deal with, but you will have to adjust combustion parameters manually when changing of the fuel. It will not be possible to cope with automatically.

Regarding flus gas return, it may be a good opportunity to enhance the temperature control of the grate, but it must be made in such way, that the flue gas return may be directed to the separate combustion zones of the grate.

Flue gas return to primary air – hydraulic grate movement system

Photo # 1: Fine Combustion at 09:47, Friday 2018/09/07

Photo # 2: Combustion with difficult fuel – ignition stopped at the right side of grate. Ignites at bottom of grate. At 11:29, Friday 2018/09/07

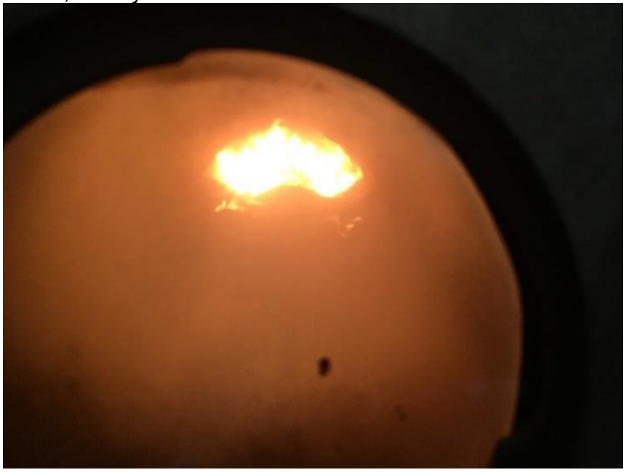
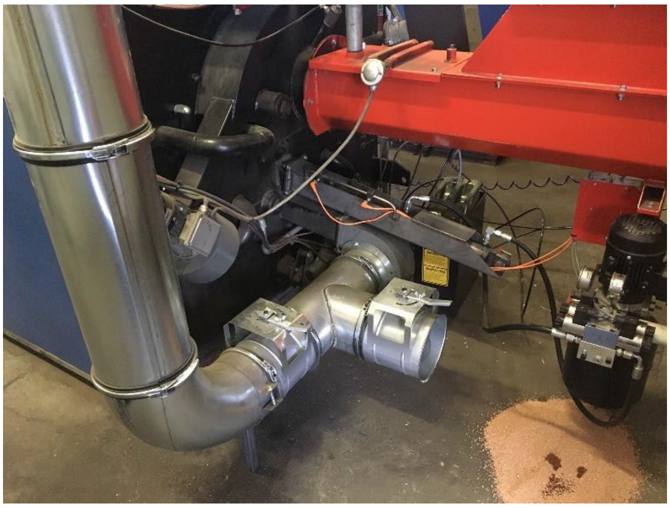


Photo #3: Combustion on difficult rice husks. Ignites at bottom of grate – only combustion on the 2 last grate steps.Ash sample # 1 taken from the end of the grate. At 12:15, Friday 2018/09/07

Rice Husks being loaded to fuel bin

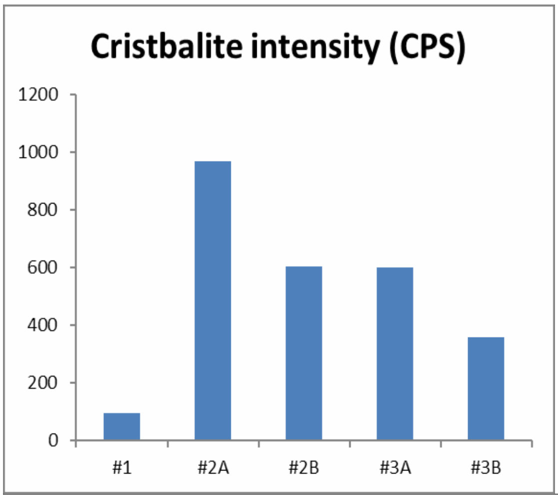


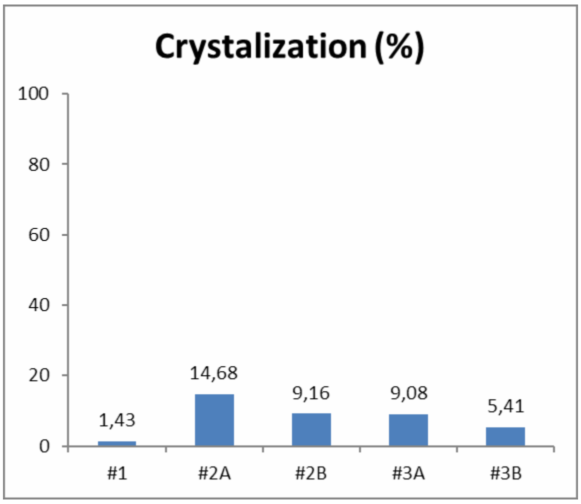
Flue gas re-circulation system

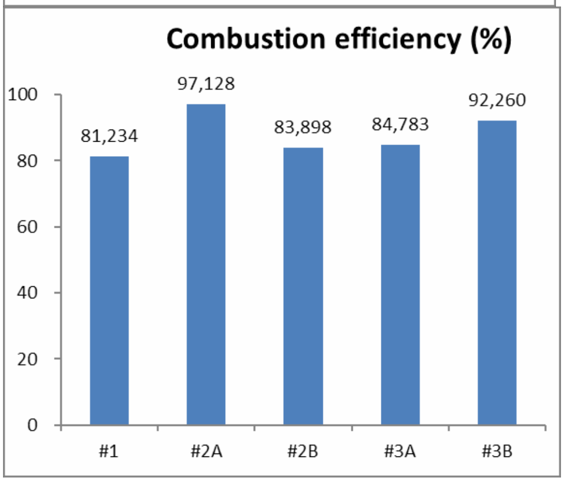
Fuel bin extraction system

Ash analysis performed by Dr. Rai, University of Akita

Dr. Rai has analyzed Linka's sample by X-ray and NC analyzer.
Ash sample # 1: Very short time combustion
Ash sample # 2A: Very fine combustion on grate – bottom of grate
Ash sample # 2B: Very fine combustion on grate – from ash bin
Ash Sample # 3A: Difficult ignition, short combustion time – from bottom grate
Ash sample # 3B: Difficult ignition, short combustion time – from ash bin







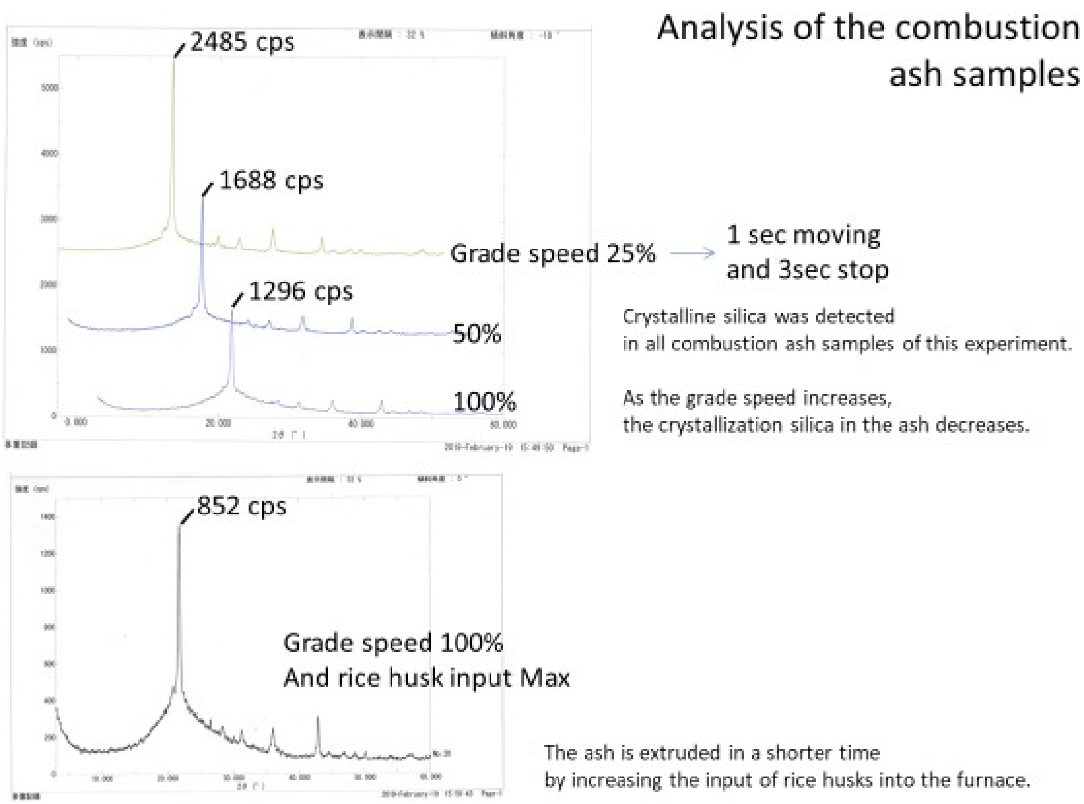
B. Combustion of Rice Husk Dec. 7th, Linka Energy A/S

The test was performed by Linka Jan E. Madsen

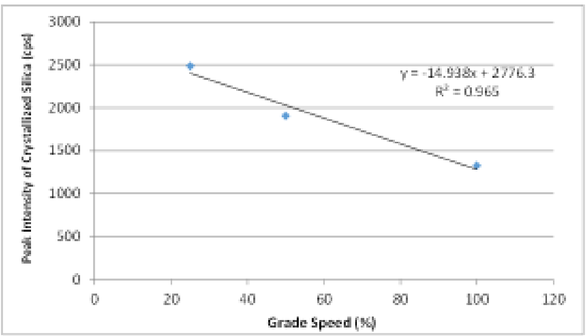
The test was supervised by Dr. Hiroki Rai, who also has prepared the analysis of the ash samples etc.

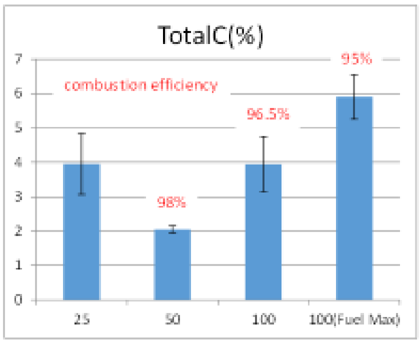
During the test, different settings of grate speed was tested.

The resulting effect on the ash crystallization is shown in the figures below.



Analysis of the combustion ash samples





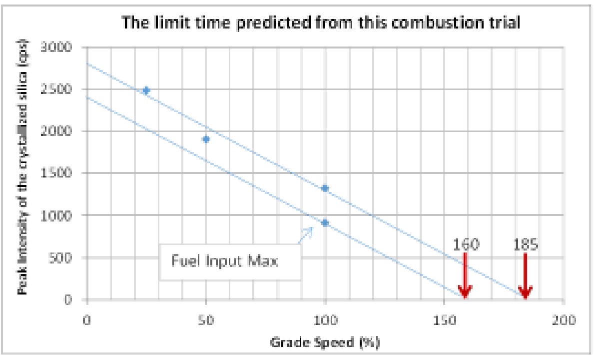
As the grade speed increases, the crystallization silica in the ash decreases linearly.

Combustion efficiency of this combustion test was 95 to 98%
→ Excess combustion.

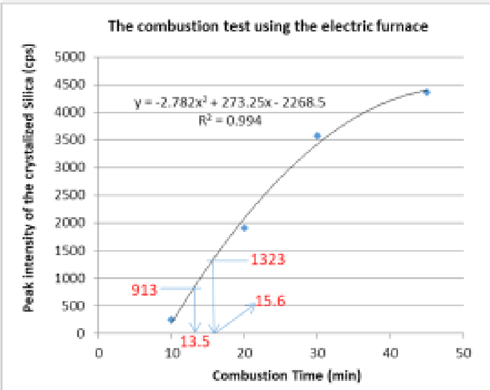
Even if the combusting rice husks is taken out in a shorter time, the combustion rate is OK, because the ash was using as a char in agriculture.

→ The ideal combustion rate is 85 to 90%

Improvement for perfect combustion of rice husks without crystallization of the silica.



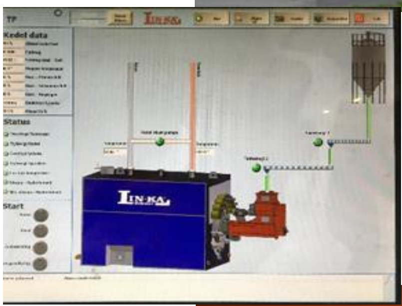
It is predicted that crystalline silica will not be produced if the grade is moved at a speed of 1.85 times when the fuel input amount is normal and 1.6 times when the fuel input amount is the maximum from the actual value of the peak intensity of the crystallized silica in this trial.

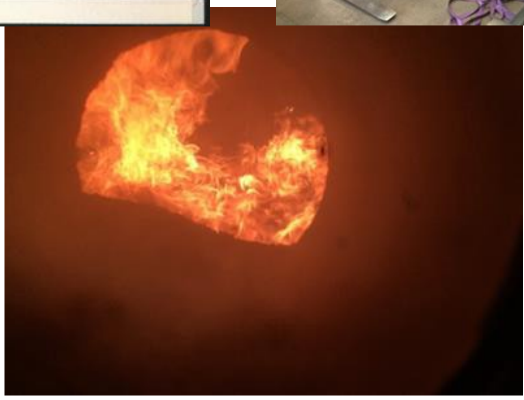


The actuator moved for 12.4 seconds in pushing and moved for 9.37 seconds in pulling, when the grade speed was setting at 100% (moving continuously).

When the water pressure actuator is changed to a twice higher speed, the crystalized silica will not be produced.

Our request
Is it possible moving the grade for 6 seconds in pushing and for 4.5 seconds in pulling by increasing the water pressure of the actuator?


Kedel data
Status
Start



Combustion of Rice Husk - by use of Danish Straw Boiler Technology

Danish technology for combustion of straw can under certain circumstances perform combustion of rice husk with acceptable efficiency and little crystallization of the silica.

The project has not succeeded in showing a continuous operation with certainty of non-crystallized ash and it still remains to find the control parameters to automatically optimize the combustion for the minimal crystallization.

To fulfil to objective of the test project it is necessary to perform further test and improving some of the measures introduced to optimize the project.

Danske teknologi til forbrænding af halm kan under visse omstændigheder kan forbrænde ris-avner med en acceptabel effektivitet og begrænset krystallisation af silicaen.

Projektet har ikke været i stand til at vise en kontinuerlig drift med sikkerhed for ikke-krystalliseret aske, og det resterer stadig at finde kontrolparametre for automatisk at kunne optimere forbrændingen til minimal krystallisation i stedet for optimal forbrænding mht. virkningsgrad og røggasemissioner, idet der ikke findes mulighed for on-line målinger af krystalliseringen.

For at opfylde målsætningen for testprojektet er det nødvendigt at udføre yderligere test og forbedre nogle af de udførte tiltag for at optimere projektet.

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Protection Agency
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