Joint Crediting Mechanism Proposed Methodology Form

Cover sheet of the Proposed Methodology Form

Form for submitting the proposed methodology

Host Country	Mongolia
Name of the methodology proponents submitting this form	KANDEN PLANT Co., Inc. NICHIAS Co., Inc.
Sectoral scope(s) to which the Proposed Methodology applies	1. Energy industries
Title of the proposed methodology, and version number	Plant efficiency improvement of through thermal insulation installation by application of thermal insulation materials (Ver1.0)
List of documents to be attached to this form (please check):	☐The attached draft JCM-PDD: ☒Additional information Appendix 1: Identification method of reference radiation heat quantity and thermal insulation efficiency by the project thermal insulation material (which are parameters fixed ex ante) Appendix 2: Identification method of reference radiation heat quantity and initial thermal insulation efficiency by the project thermal insulation material (which are parameters fixed ex ante) Appendix 3: Calculation equation of radiation heat quantity based on JIS A9501 Appendix 4: Identification of decreasing rate from initial thermal insulation efficiency of the project thermal insulation material according to measurement data thermal conductivity for project thermal insulation material in conservative manner
Date of completion	16th February, 2015

History of the proposed methodology

Version	Date	Contents revised
1.0	1st September,	First Version

	2014	
2.0	13th January, 2015	Second Version
3.0	16th February, 2015	Third Version

A. Title of the methodology

Plant efficiency improvement of through thermal insulation installation by application of thermal insulation materials (Ver3.0)

B. Terms and definitions

Terms	Definitions
ASTM C1728-12	ASTM is the acronym of American Society for Testing and Materials and an international standard organization. ASTM standards are produced by the world largest, unofficial and noncommercial organization and used worldwide even it is arbitrary standards. ASTM C1728-12 standardizes the specification for Flexible Aerogel Insulation.
Boiler efficiency	Boiler efficiency is formulated as follows that means boiler heat efficiency (ratio of input and output heat quantity of boiler). Boiler efficiency = (Heat quantity of generated main steam- Heat quantity of feed-water)/ Heat quantity of consumed boiler fuel or Boiler efficiency = (Heat quantity of consumed boiler fuel–Heat loss quantity of boiler) /Heat quantity of consumed boiler fuel Heat loss of boiler is caused by heat loss of boiler exhaust gases, radiation heat loss of boiler surface, unburnt composition in fly ashes, unburnt composition of bottom ashes, energy loss in start-up of boiler, etc.

Infrared thermography	The equipment which displays image of surface temperature distribution that is converted from detected infrared energy emitted from object to temperature though it is unable to directly measure radiation heat quantity emitted form the surface of object. It has following features: - Non-contact measurement enables to measure surface temperature from remote location. - It provides real-time measurement.
Heat flow meter	The equipment which measures heat flow quantity. The intense of heat movement is called as heat flow (heat energy) and dimensioned as quantity of heat energy per unit area (W/m2). It is measured by difference of temperatures between the sides of flat-board-shaped heat resistor that is proportioned to quantity of heat flow when the heat flow is passed through the heat resistor. An antecedent of temperature variation is given by using heat flow meter as heat movement and quantity shows visibly though thermocouples or thermography are unable to show process of the temperature variation (heat is emitted or absorbed).

C. Summary of the methodology

Items	Summary
GHG emission reduction measures	The objective of the project activity is to reduce heat quantity radiated from surfaces of heat/power supply facilities at thermal power plant due to thermal insulation installation by application of thermal insulation materials. The coal consumption for boiler fuel will reduce by thermal insulation installation. Thus the project activity leads to GHG emission reduction. (The amount of heat and power supplied by the thermal power plant in project case is thought to be equivalent to the one in reference case.)

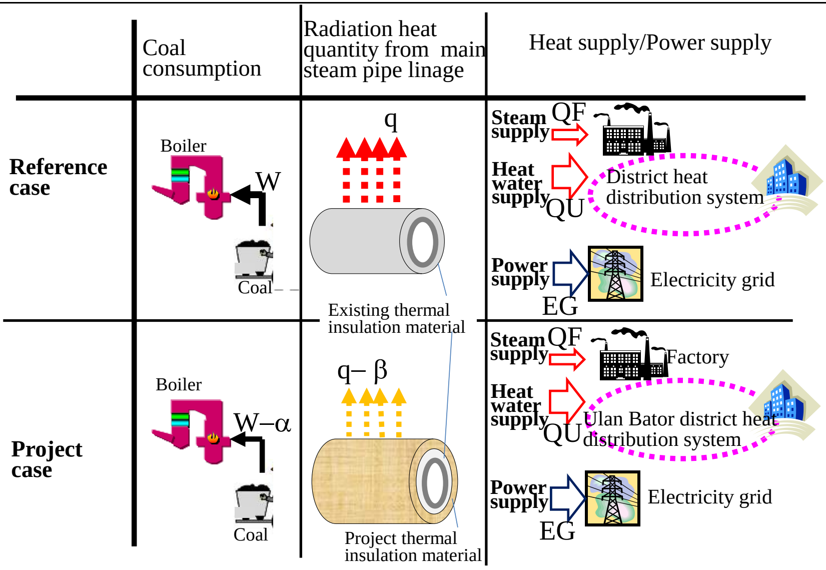


Figure 1 Imaging comparison between project case and reference one

Calculation of reference emissions

The reference emissions are calculated with the following equations.

$$RE_y = QR_{RE,y} \,/\, \eta_{boiler} \times EF_{CO2,coal}$$

$$QR_{RE,y} = \sum_{n} QR(n)_{RE,y}$$

$$QR(n)_{RE,y} = SA(n)_{RE,y} \times qR_{RE} \times 3600 \times OH(n)sv,_y \times 10^{-9}$$

Where;

RE_y	Reference emissions during the period of year *y*	tCO_2/y
$QR_{RE,y}$	Reference total radiation quantity during the period of year *y*	GJ/y
n	Line Number of main steam pipe linage installed by the project insulation material at the thermal power plant	
$QR(n)_{RE,y}$	Reference total radiation quantity on main steam pipe line No. *n* during the period of year *y*	GJ/y
η_{boiler}	Boiler efficiency	Non-dimension
$EF_{CO2,coal}$	CO_2 emission factor of coal	tCO_2/GJ

Calculation of project emissions

The project emissions are calculated with the following equations.

$$PE_y = QR(n)_{PJ,y} \,/\, \eta_{boiler} \times EF_{CO2,coal}$$

$$Q_{PJ,y} = \sum_{n} QR(n)_{PJ,y}$$

$$QR(n)_{PJ,y} = SA(n)_{PJ,y} \times qR(n)_{PJ,y} \times 3600 \times OH(n)sv,_y \times 10^{-9}$$

<table>
<tr><td></td><td>Where;
<table>
<tr><td>PE_y</td><td>Project emissions during the period of year y</td><td>tCO_2/y</td></tr>
<tr><td>$QR_{PJ,y}$</td><td>Project total radiation quantity during the period of year y</td><td>GJ/y</td></tr>
<tr><td>n</td><td>Line Number of main steam pipe linage installed by the project insulation material at the thermal power plant</td><td></td></tr>
<tr><td>$QR(n)_{PJ,y}$</td><td>Project total radiation quantity on main steam pipe line No. n during the period of year y</td><td>GJ/y</td></tr>
<tr><td>η_{boiler}</td><td>Boiler efficiency</td><td>Non-dimension</td></tr>
<tr><td>$EF_{CO2,coal}$</td><td>CO_2 emission factor of coal</td><td>tCO_2/GJ</td></tr>
</table></td></tr>
<tr><td>Monitoring parameters</td><td>• Steam flow hours in main steam pipe line [hours]
• Total area where project thermal insulation materials have stripped [m^2]
• Thermal conductivity of new project thermal insulation material (before insulation) [W/m･K]
• Thermal conductivity of used project thermal insulation material after y years later since installation [W/m･K]

(Parameters fixed after 1st verification)
The following parameters are not needed to monitor but cannot be parameters fixed ex ante.
• Length installed by the project thermal insulation material
• Thickness constructed by the project thermal insulation material</td></tr>
</table>

D. Eligibility criteria

This methodology is applicable to projects that satisfy all of the following criteria.

Criterion 1	The project activity is to reduce heat quantity radiated from surfaces of existing main steam pipe system in coal-fired thermal power plant due to thermal insulation installation by application of high performing thermal insulation materials.
Criterion 2	Installation works can be carried out without removing existing thermal insulation materials (e.g. asbestos).

<table>
<tr><td>Criterion 3</td><td>Non-asbestos Flexible Aerogel thermal insulation is to be employed in order to ensuring appropriate installation works which prevent scatter of asbestos. Furthermore, fluorocarbon foaming agent is not also to be contained in the material from a standpoint of environmental integrity.</td></tr>
<tr><td>Criterion 4</td><td>Thermal insulation materials employed for project has apparent thermal lower than ones defined by ASTM C1728-12 and ones calculated by the following approximate expression extrapolated to high temperature range based on ones defined by ASTM C1728-12.

<u>Thermal conductivity of Flexible Aerogel thermal insulation defined by ASTM C1728-12</u>
<table><tr><th>Mean Temperature [°C]</th><th>Apparent thermal conductivity [W/m･K]</th></tr><tr><td>23.9</td><td>0.021</td></tr><tr><td>37.8</td><td>0.022</td></tr><tr><td>93.3</td><td>0.023</td></tr><tr><td>149</td><td>0.025</td></tr><tr><td>204</td><td>0.029</td></tr><tr><td>260</td><td>0.032</td></tr><tr><td>316</td><td>0.036</td></tr><tr><td>371</td><td>0.043</td></tr></table>
<u>Approximate expression extrapolated to high temperature range based thermal conductivity of Flexible Aerogel thermal insulation defined by ASTM C1728-12</u>
$\lambda = 2.771E{-}10 \cdot \theta^3 - 3.098\,E{-}9 \cdot \theta^2 + 3.328\,E{-}5 \cdot \theta + 0.02034$

where;
λ : Thermal conductivity of Flexible Aerogel thermal insulation [W/m･K]
θ : Temperature [°C]</td></tr>
<tr><td>Criterion 5</td><td>Thermal insulation materials employed for project covers operating high temperature range for the project as the manufacturer’s catalog value.</td></tr>
</table>

E. Emission Sources and GHG types

Reference emissions	
Emission sources	GHG types
Coal consumption of the boiler fuel burned for generating heat quantity that would be radiated from the surface of the existing thermal insulation material at the project installation area of main steam pipe	CO_2

linage in the absence of the project activity.	
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA
Project emissions	
Emission sources	GHG types
Coal consumption of the boiler fuel burned for generating heat quantity radiated from the surface of the project thermal insulation at the project installation area of main steam pipe linage	CO_2
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA
NA	NA

F. Establishment and calculation of reference emissions

F.1. Establishment of reference emissions

At thermal power plants of Mongolia, the current situation without heat-retention activity for heat/power supply facilities will continue in the absence of JCM scheme, because a lot of additional costs are required to do high performing thermal insulation installation by the following reasons;

- Since the price of coal consumed for domestic use is very cheap in Mongolia, Saving activity for coal consumption is not economically attractive.
- For plant efficiency improvement, there are some important measures which are given priority over a thermal insulating one. A thermal insulating one is the latest option.
- In case of installing cheap and low-performing insulation materials, it is required to install thickly for sectional thickness of main steam pipes and causes problems in terms of durability of main steam pipes and work safety.

Under these circumstances, as for quantifying reference emission, we cannot see scenarios situated between BaU and the project one in case of the project activity. In other words, we cannot differentiate reference from BaU in term of “scenario”. So, for this project activity,

quantifying reference emission, we identified values for parameters involved in calculation equation of reference emissions in conservative manner, in order to differentiate reference emission from BaU one. Therefore, the methodology results in a net reduction of emissions, since reference emissions are secured to be lower than the BaU emissions.
Therefore, the methodology results in a net reduction of emissions, since reference emissions are secured to be lower than the BaU emissions.

F.2. Calculation of reference emissions

The reference emissions are calculated with the following equations.

$RE_y = QR_{RE,y} / \eta_{boiler} \times EF_{CO2,coal}$

$QR_{RE,y} = \sum_n QR(n)_{RE,y}$

$QR(n)_{RE,y} = SA(n)_{RE,y} \times qR_{RE} \times 3600 \times OH(n)sf,_y \times 10^{-9}$

$SA(n)_{RE,y} = SA(n)_{ExI} \times (1 - SA(n)_{PJI\text{-}str,y} / SA(n)_{PJI\text{-}ins})$

$SA(n)_{ExtI} = (d(n)_{ExtP} + 2\times t(n)_{ExtI}) / 1000 \times \pi \times l(n)_{PJI}$

Where;

RE_y	Reference emissions during the period of year *y*	tCO_2/y
$QR_{RE,y}$	Reference total radiation quantity during the period of year *y*	GJ/y
n	Line Number of main steam pipe linage installed by the project insulation material at the thermal power plant	
$QR(n)_{RE,y}$	Reference total radiation quantity on main steam pipe line No. *n* during the period of year *y*	GJ/y
η_{boiler}	Boiler efficiency	Non-dimension
$EF_{CO2,coal}$	CO_2 emission factor of coal	tCO_2/GJ

$SA(n)_{RE,y}$	Reference radiation surface area for main steam pipe line No. *n* during the period of year *y*	m^2
qR_{RE}	Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage at the thermal power plant	W/m^2
$OH(n)sf,_y$	Steam flow hours in main steam pipe line No. *n* during the period of year *y*	hours/y

$SA(n)_{ExtI}$	Surface area covered by existing thermal insulation material where will be installed by the project thermal insulation material for main steam pipe line No. *n*	m^2
$SA(n)_{PJI\text{-}ins}$	Surface area covered by the project thermal insulation material for main steam pipe line No. *n*	m^2
$SA(n)_{PJI\text{-}str,y}$	Total area where project thermal insulation materials have stripped on main steam pipe line No. *n* by the end of the year *y*	m^2

$d(n)_{ExtP}$	Outside diameter of the existing pipe for main steam pipe line No. *n*	mm
$t(n)_{ExtI}$	Thickness covered by the existing thermal insulation material on main steam pipe line No. *n*	mm
$t(n)_{PJI}$	Thickness installed by the project thermal insulation material for main steam pipe line No. *n*	mm
$l(n)_{PJI}$	Length installed by the project thermal insulation material for main steam pipe line No. *n*	m

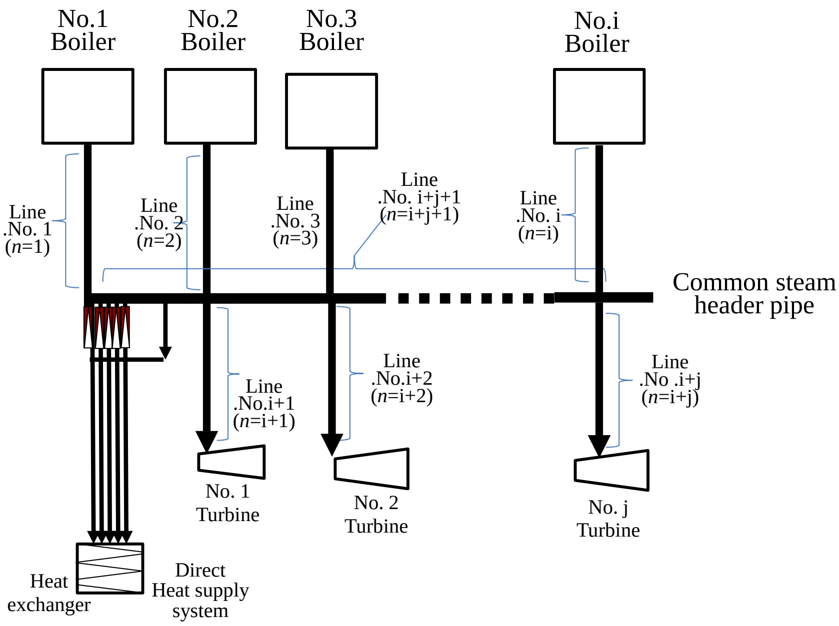


Figure 2 At the thermal power plat which has i boilers of i number and turbines of j number) example for main steam pipe linage No. (In case that project insulation materials are installed for all lines)

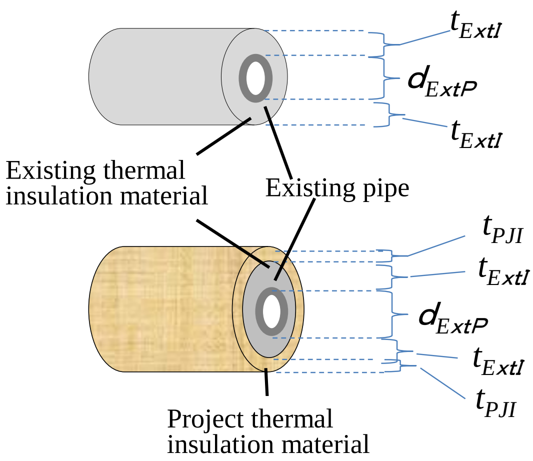


Figure 3 Imaging figure of existing pipe, existing thermal insulation material and project thermal insulation material

G. Calculation of project emissions

The project emissions are calculated with the following equations.

$$PE_y = QR(n)_{PJ,y} / \eta_{boiler} \times EF_{CO2,coal}$$

$$Q_{PJ,y} = \sum_n QR(n)_{PJ,y}$$

$$QR(n)_{PJ,y} = SA(n)_{PJ,y} \times qR(n)_{PJ,y} \times 3600 \times OH(n)sf,_y \times 10^{-9}$$

$$SA(n)_{PJ,y} = SA(n)_{PJI\text{-}ins} \times (1 - SA(n)_{PJI\text{-}str,y} / SA(n)_{PJI\text{-}ins})$$

$$SA(n)_{PJI\text{-}ins} = (d(n)_{ExtP} + 2\times t(n)_{ExtI} + 2\times t(n)_{PJI}) / 1000 \times \pi \times l(n)_{PJI}$$

$$qR(n)_{PJ,y} = qR_{RE} \times \{1 - f(n)_{PJI\text{-}eff} \times (1 - f_{PJI\text{-}dec,y})\}$$

$$f_{PJI\text{-}dec,y} = \text{Maximum } \{(\lambda_{PJI,y} - \lambda_{PJI,0})/\lambda_{PJI,0},\ 0\}$$

Where;

PE_y	Project emissions during the period of year *y*	tCO_2/y
$QR_{PJ,y}$	Project total radiation quantity during the period of year *y*	GJ/y
n	Line Number of main steam pipe linage installed by the project insulation material at the thermal power plant	
$QR(n)_{PJ,y}$	Project total radiation quantity on main steam pipe line No. *n* during the period of year *y*	GJ/y
η_{boiler}	Boiler efficiency	Non-dimension

$EF_{CO2,coal}$	CO_2 emission factor of coal	tCO_2/GJ

$SA(n)_{PJ,y}$	Project radiation surface area for main steam pipe line No. *n* during the period of year *y*	m^2
$qR(n)_{PJ,y}$	Project radiation heat quantity (after thermal insulation installation) from main steam pipe linage at the thermal power plant	W/m^2
$OH(n)sf_{,y}$	Steam flow hours in main steam pipe line No. *n* during the period of year *y*	hours/y

$SA(n)_{ExtI}$	Surface area covered by existing thermal insulation material where will be installed by the project thermal insulation material for main steam pipe line No. *n*	m^2
$SA(n)_{PJI\text{-}ins}$	Surface area covered by the project thermal insulation material for main steam pipe line No. *n*	m^2
$SA(n)_{PJI\text{-}str,y}$	Total area where project thermal insulation materials have stripped on main steam pipe line No. *n* by the end of the year *y*	m^2

$d(n)_{ExtP}$	Outside diameter of the existing pipe for main steam pipe line No. *n*	mm
$t(n)_{ExtI}$	Thickness covered by the existing thermal insulation material on main steam pipe line No. *n*	mm
$t(n)_{PJI}$	Thickness installed by the project thermal insulation material for main steam pipe line No. *n*	mm
$l(n)_{PJI}$	Length installed by the project thermal insulation material for main steam pipe line No. *n*	m

qR_{RE}	Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage at the thermal power plant	W/m^2
$f(n)_{PJI\text{-}eff}$	Initial thermal insulation efficiency by the project thermal insulation material for main steam pipe line No. *n*	Non-dimension
$f_{PJI\text{-}dec,y}$	Decreasing rate from initial thermal insulation efficiency of the project thermal insulation material for main steam pipe line No. *n*	Non-dimension

$\lambda_{PJI,0}$	Thermal conductivity of new project thermal insulation material (before installation)	W/m・K

$\lambda_{PJI,y}$	Thermal conductivity of used project thermal insulation material after *y* years later since installation	W/m・K

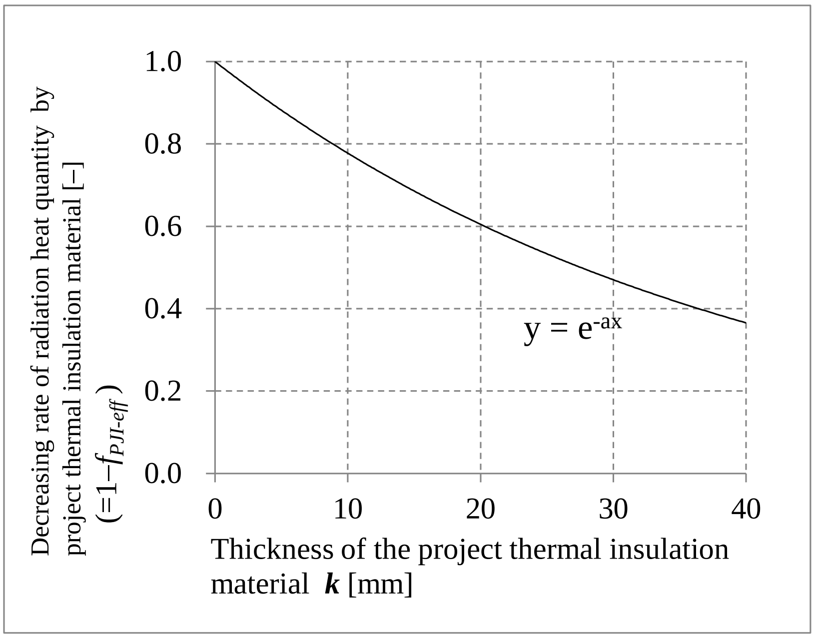


Figure 4 Heat insulating effect by the project thermal insulation material according to installed thickness

H. Calculation of emissions reductions

The emission reductions are calculated from the reference emissions and the project emissions.

$ER_y = RE_y - PE_y$

Where;

ER_y	GHG emission reductions during the period of year *y*	tCO_{2e}/y
RE_y	Reference emissions during the period of year *y*	tCO_2/y
PE_y	Project emissions in during the period of year *y*	tCO_2/y

I. Data and parameters fixed *ex ante*

The source of each data and parameter fixed *ex ante* is listed as below.

Parameter	Description of data	Source
η_{boiler}	Boiler efficiency	Default value. 1.0 (Most conservative value) is applied to the

		parameter
$EF_{CO2,coal}$	CO_2 emission factor of coal	Default value. Default value of CO_2 emission factor for "Lignite", according to "2006 IPCC Guidelines for National Greenhouse Gas Inventory"
d_{ExtP}	Outside diameter of the existing pipe	Well-known value before the prior to the project implementation according to drawing for design according to the thermal power plant
t_{ExtI}	Thickness covered by the existing thermal insulation material	Well-known value before the prior to the project implementation according to equipment specification according to the thermal power plant
qR_{RE}	Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage	Parameter fixed ex ante identified according to Appendix 1 and Appendix 2
$f_{PJI\text{-}eff}$	Initial thermal insulation efficiency by the project thermal insulation material	Parameter fixed ex ante identified according to Appendix 1 and Appendix 2

Appendix 1

Study procedure for identification of reference radiation heat quantity and thermal insulation efficiency by the project thermal insulation material (which are parameters fixed ex *ante*)

In order to identifying values of 2 parameters fixed *ex ante*, the study was carried out as the following procedure;

For the study, Pyrogel XT (Project thermal insulation material for the proposal project) has actually installed for sample on main steam pipes at CHP3 (high pressure unit) and CHP4,
in order to identifying values of the following 2 parameters which are parameters fixed *ex ante* for the proposed methodology;
- Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage (qR_{RE})
- Thermal insulation efficiency by the project thermal insulation material ($f_{PJI\text{-}eff}$)

Then, for the quantification work, two measuring equipments (infrared thermography and heat flow meter) were employed.
• Infrared thermography cannot directly measure radiation heat quantity from the surface of the measured object, but can provide a radiation heat distribution from a wide area (can indirectly convert to radiation heat quantity (heat flow) according to equations based on JIS 9501.).
• Heat flow meter can directly measure radiation heat quantity (heat flow) from the surface of the measured object for pinpoint (for only area attached by the sensor), but cannot measure widely.

The surface temperature distribution on the existing thermal insulation material at CHPs in Mongolia ranges in scope, because the content of asbestos in the existing thermal insulation material are considerably different with location and we can see many deterioration points on them.
Under these circumstances, infrared thermography is better for the measurement, however it cannot measure. So, we values fluctuating radiation heat quantity, taking advantage of strong points of both equipments.

For sampling installation position of project thermal insulation material, each 3 positions are established in CHP3 (high pressure unit) and CHP4 according to site conditions (for safety and for positions where are not comparatively different with location), as the following figures;

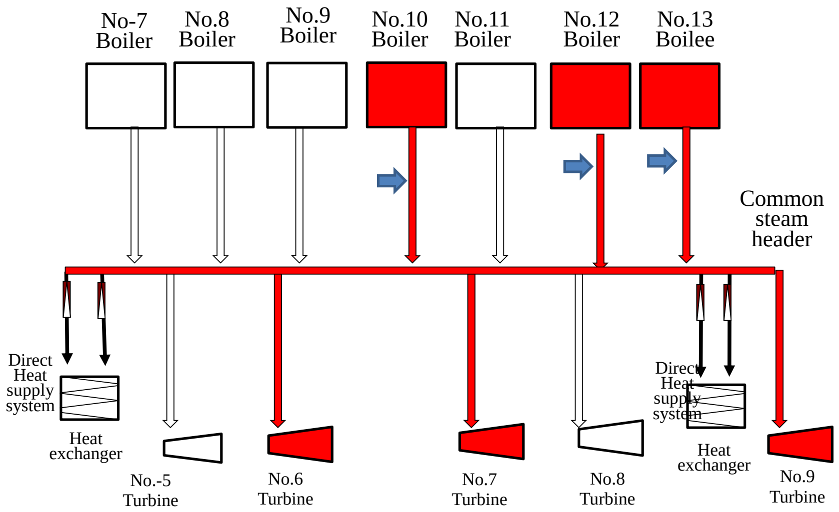


Figure AP1-1.1 Sampling installation positions of project thermal insulation material at CHP3 (high pressure unit)[1]

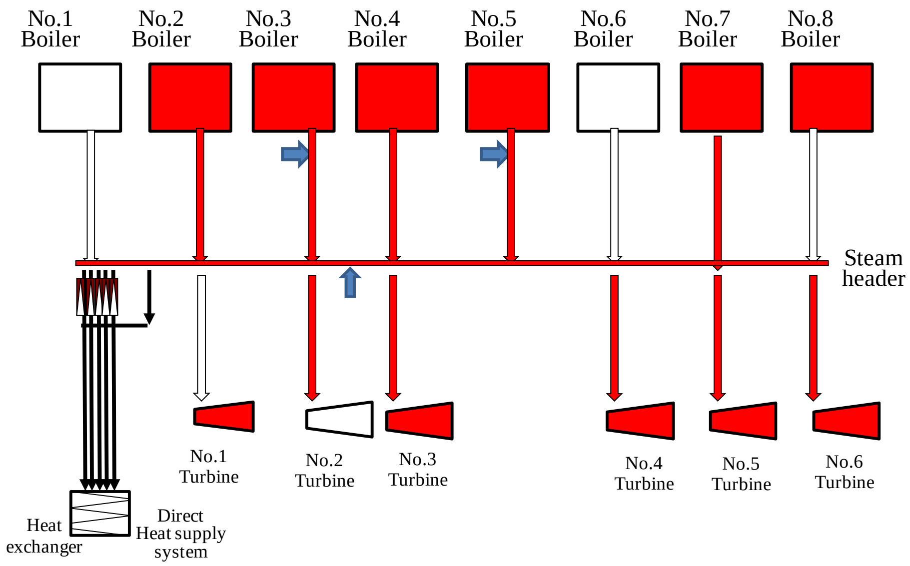


Figure AP1-1.2 Sampling installation positions of project thermal insulation material at CHP3 (high pressure unit)

At each position of 6 ones, 4 areas (1 position for non-installation and 3 installation positions for thickness of 10mm, 20mm and 40mm) are set.

At same positions of each area, the following measurements were performed with and without

[1] Facilities and main steam pipes (filled with red) are on operation status.

installation of the project thermal insulation material;[2]

• Taking thermographic images by infrared thermography (including measuring surface temperature and ambient temperature by contact type thermo-meter) just before measurement of heat flow meter

• Measuring radiation heat quantity by heat flow meter (Measuring frequency: Continuously, Recording frequency: Every second, Measuring length: 1-2 hours)

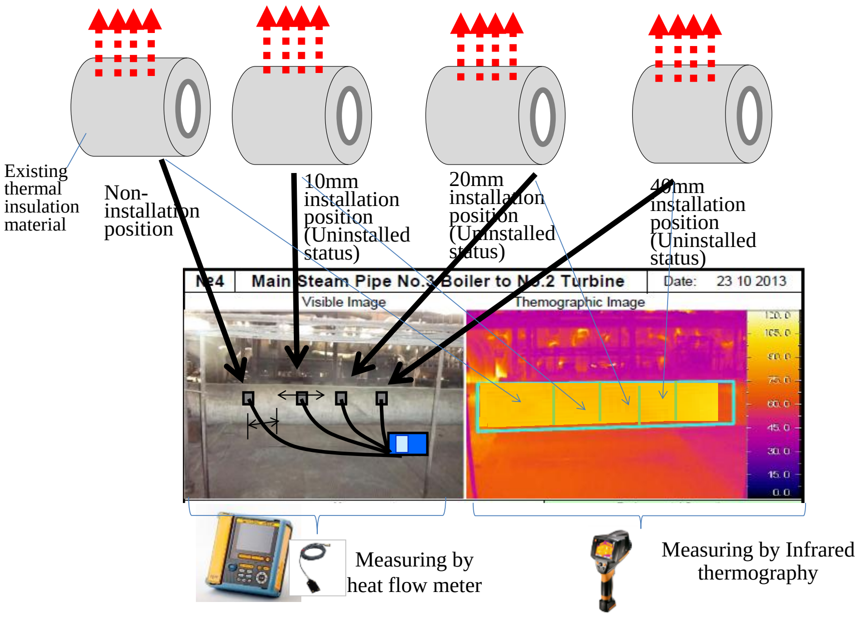


Figure AP1-2.1 Imaging figure of measurement without sampling installation of the project thermal insulation material at each area

[2] For the study, wind velocity around sampling installation position was not measured and it is assumed that wind velocities equals to 0, because of indoor facilities. Although wind velocities were measured in FS of FY2013, all data for wind velocities was 0 m/s (below detection limit of the air speed meter).

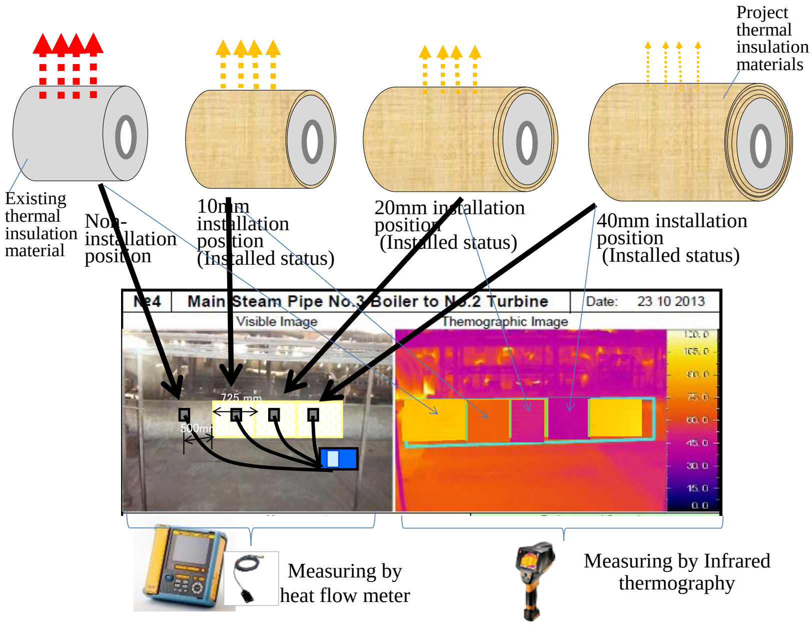
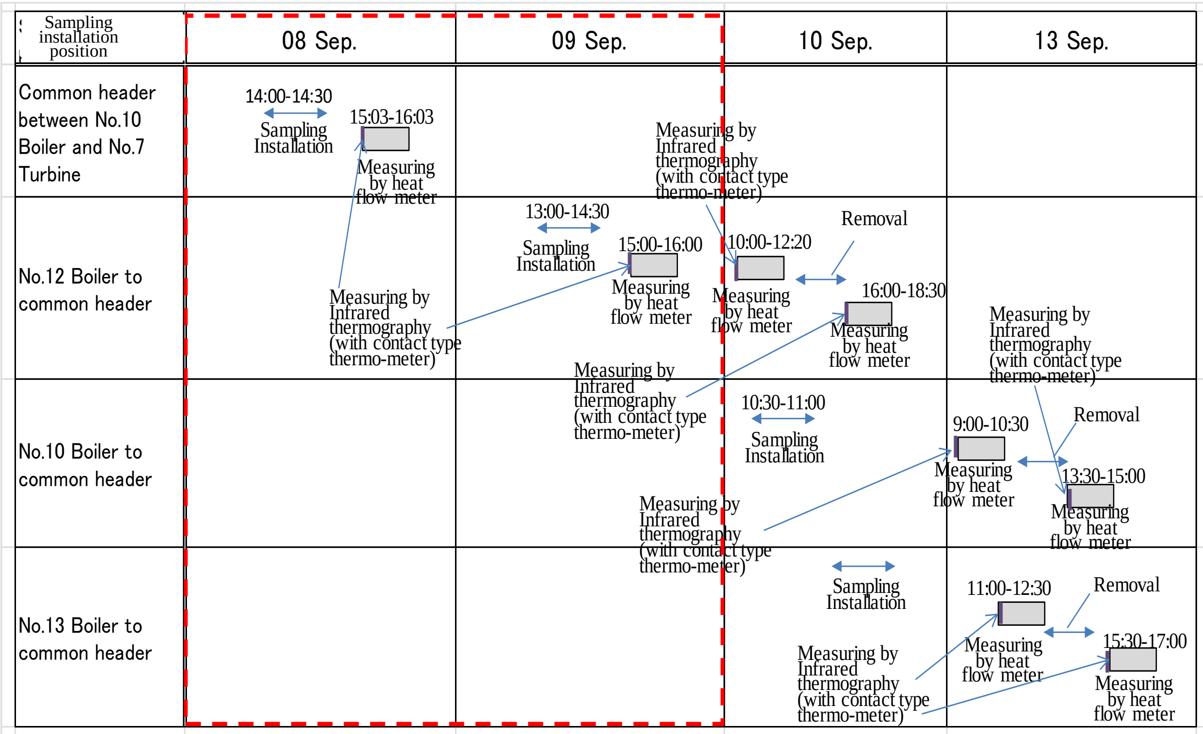


Figure AP1-2.2 Imaging figure of measurement with sampling installation of the project thermal insulation material at each area



Works for sampling installation of project thermal insulation material and measurement were carried out as the following tables;

Table AP1-1.1 Process of works for sampling installation of project thermal insulation material and measurement (at CHP3 high pressure unit)[3]

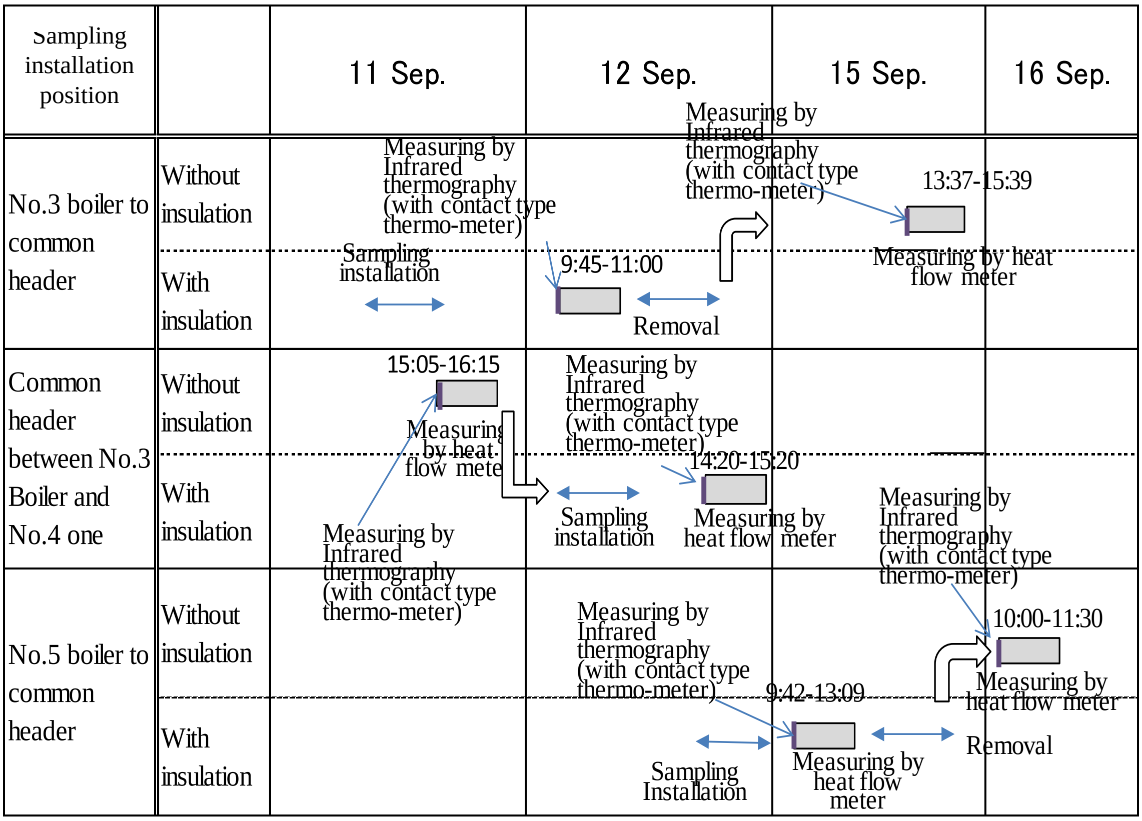


Table AP1-1.2 Process of works for sampling installation of project thermal insulation material and measurement (at CHP4)

Operation status for related boilers/turbines during measurement by infrared thermography and heat flow meter are briefly as the following tables;

Table AP1-2.1 Operation status during measurement by infrared thermography and heat flow meter (at CHP3 high pressure unit)

[3] Sampling installation and measuring works were carried out by initial planed procedure during 2 days after the works started. However, initial procedure for works was changed according to site situations, confirming measured data. The data measured by initial procedure are excluded from available ones to analyze and identify 2 parameters fixed ex ante.

		08 Sep.		09 Sep.		10 Sep.			13 Sep.			
Measuring point	Measuring parameter	Boiler or Turbine No.	15:03-16:03	Boiler or Turbine No.	15:00-16:00	Boiler or Turbine No.	10:00-12:20	16:00-16:30	Boiler or Turbine No.	9:00-10:30 13:30-15:00	Boiler or Turbine No.	11:00-12:30 15:30-17:00
Boiler outlet	Steam pressure [ata]	No, 10	98-99	No, 12	98-99	No, 12	96-99	98-99	No, 10	97-100	No, 13	97-99
	Steam Temp. [℃]		531-538		531-537		530-538	526-532		529-540		533-542
	Steam flow rate [t/h]		149-156		141-156		145-156	148-166		149-157		142-146
Turbine inlet	Steam pressure [ata]	No, 7	90-91									
	Steam Temp. [℃]		526-533									
	Steam flow rate [t/h]		138-139									
Common header	Steam pressure [ata]	No.10 Boiler-No.7 Turbine	90									
Operation Boiler		No.10,12,13		No.10,12,13		No.10,12,13			No.10,12,13			
Operation Turbine		No.6, 7, 9		No.6, 7, 9		No.6, 7, 9			No.6, 7, 9			

Designed Value

	Boiler outlet	Turbine inlet (No.5-8)	Turbine inlet (No.9)
Steam pressure [kg/cm^2]	100	90	88
Steam Temp. [℃]	540	535	535
Steam flow rate [t/h]	220		
Output [MW]		22	50

Table AP1-2.2 Operation status during measurement by infrared thermography and heat flow meter (at CHP4)

		11 Sep.				12 Sep.		15 Sep.				16 Sep.	
Measuring point	Measuring parameter	Boiler No.	15:00-16:00			Boiler No.	10:00-12:00 / 14:30-16:00	Boiler No.	9:23-13:00	Boiler No.	13:35-15:35	Boiler No.	10:00-11:30
Boiler outlet	Steam pressure [ata]	No, 3	139-140	No, 4	137-139	No, 3 / No.4	140/138	No, 5	138	No, 3	141	No, 5	137
	Steam Temp. [℃]		550-563		557-561		551/557		558		554		554
	Steam flow rate [t/h]		401-407		337-341		404/325		369		339		358
Operation Boiler		No.2,3,4,5,7				No.2,3,4,5,7		No.2,3,4,5,7				No.2,3,4,5,7	
Operation Turbine		No.1,3,4,5,6				No.1,3,4,5,6		No.1,3,4,5,6				No.1,3,4,5,6	

Designed Value

	Boiler outlet	Turbine inlet (No.1,6)	Turbine inlet (No.2-5)	Generator (No.1,6)	Generator (No.2-5)
Steam pressure [kg/cm^2]	140	130			
Steam Temp. [℃]	560	555			
Steam flow rate [t/h]	420				
Output [MW]		80	100	80	100

Specifications of measuring equipments used for the study are as the following tables;

Table 1-3.1 Specification of heat flow meter

Equipment	Item	Specification
Heat flow meter	Manufacturer, model	Kyoto Denshi Kogyo, HFM-215N
	Measuring item	Heat flow and temperature
	Measuring range	Heat flow: 0 to +/-99.999W/m^2 Temperature: K-thermocouple -40°C to750°C
	Selecting units	Heat flow (W/m^2) + Temperature (°C),

		Heat flow (W/m^2), Temperature(°C)
	Sampling cycle	Selecting from 200/500ms,1/2/5/10/20/30sec, 1/2/5/10/30/min,1h
	Display update	Approx. 1sec
	What to display	Selecting from waveform, bar chart, values of heat flow and waveform plus such values
	Number of sensors	Sensor constant A/B type, sensor constant A type that requires temperature data up to 8, sensor constant A type that requires no temperature data up to 16
	Internal memory	16MB Stores data of 55hours with 8 seconds of sensor constant A/B type at sampling rate of 1 second
	External memory device	Compact flush type II, SD card, USB flash drive (copy only)
	External communication	Ethernet (10BASE-T/10BASE-TX), web server, FTP server, FTP client e-mail transmitting functions compliant with USB 1.1, RS-232C, RS-485
	Power source	Rechargeable battery: lasts for approx.. 7 hours of continuous use on a full change of approx.. 8 hours, (RT 25°C, measurement cycle of 5 minutes or more, backlighting auto off in 5 minutes or less, data communication not in use.) comes with AC adapter (AC 100 to 240V) as standard
	Ambient conditions	Temperature: 0 to 50°C (0 to 40°C when using battery), Humidity: 5 to 85%RH
	Dimensions	Approx. 155(W)×155(H)×55(D)mm (not including projection portions and rubber cushions)
	Weight	Approx. 800g (not including projection portions and rubber cushions)
Heat flow sensor	Manufacturer, model	Kyoto Denshi Kogyo, KR2
	Usage	General-purpose low heat sensor for surface of insulation

	Standard heat flow range	12-3,500W/m^2
	Standard temperature range	-40°C to 150°C
	Dimensions of sensing part	50(W)×100(H)mm

Heat flow meter

Heat flow sensor

Figure 1-3.2. Appearance of heat flow meter

Table 1-3.2 Specification of thermometer infrared thermography

Item	Specification
Maker/Type	Nippon Avionics Co., Ltd/　InfReC R300
Measuring range (Temp.)	-40°-500°C
Setting ability for Temp.	0.03°C at 30°C
Accuracy for temp.	±0.1°C
Frame rate	60Hz
Pixel　No.	640×480pixel/320×240pixel
Angle of view	44°×34°
Operating environment for temp. and humidity	-15°C-50°C、Under 90%RH

Table 1-3.3 Specification of contact type thermometer

Item	Specification
Maker/Type	ANRITSU/ HFT-50
Measuring range (Temp.)	-99.9°C -499.9°C
Setting ability for Temp.	±0.1°C
Accuracy for temp.	Over 0°C: ±(Indicated value×0.05%+0.2) °C Under 0°C: ±0.5°C

Appendix 2

Identification method of reference radiation heat quantity and initial thermal insulation efficiency by the project thermal insulation material (which are parameters fixed ex ante)

Outcomes of the study (by Appendix 1) are as follows;

<u>Comparison of radiation heat quantity between measurement value by heat flow meter and calculation value according to thermographic image analysis by infrared thermography</u>

At 6 sampling installation areas of project thermal insulation material (3 ones for CHP3 and 3 ones for CHP4), both values of radiation heat quantity data (by the following 2 methods) are compared.

• Measured values of radiation heat quantity by heat flow meter (for only area attached by the sensor)

• Calculation values of radiation heat quantity based on JIS A9501 ”Standard practice for thermal insulation works”[4] according to thermographic image analysis for data measured by infrared thermography and contact type thermo-meter (just before measuring by heat flow meter starts)

For thermographic image analysis, pixels for only area attached by the heat flow sensor are extracted of ones within the view as the following figure. Then, the average surface temperatures for the extracted pixels was calculated and converted to the radiation heat quantity from the extracted area based on equation JIS A9501.

Figure AP2-1.1 Example of thermographic image pixels extracted for only area attached by the heat flow sensor without installation of project thermal insulation material

4 Please refer to Appendix 3

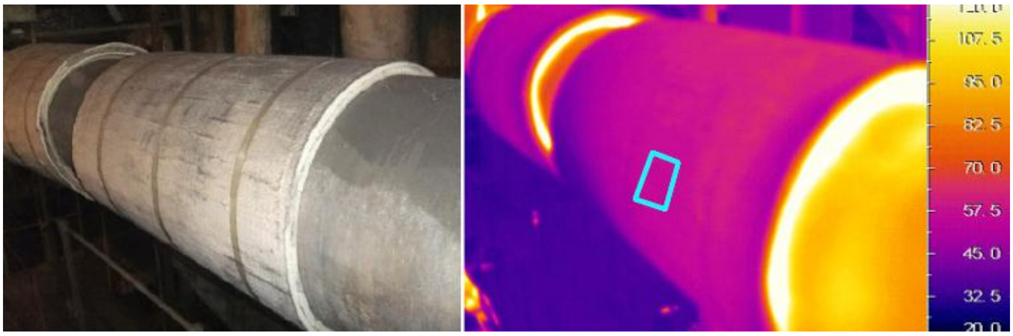


Figure AP2-1.2 Example of thermographic image pixels extracted for only area attached by the heat flow sensor with installation of project thermal insulation material

Values identified by both methods and the correlation chart between both values are as follows;

Table AP2-1 Comparison of values for radiation heat quantity identified by heat flow meter and infrared thermography

CHP name	Sampling installation area	Setting position	Sampling installation status	Measurement date	Related data of infrared thermography									Heat flow meter
					Pipe diameter information					Ambient Temp.	Wind speed	Surface temp.	Calculation values of radiation heat quantity based on JIS A9501	Measured values of radiation heat quantity by heat flow meter (Only area attached by the heat flow sensor)
					Outside diameter of the existing pipe	Thickness covered by the existing thermal insulation material	Thickness installed by the project thermal insulation material	Total outside diameter	Pipe direction			Only area attached by the heat flow sensor	Only area attached by the heat flow sensor	
					mm	mm	mm	m		°C	m/s	°C	W/m²	W/m²
CHP3 high pressure unit	No.12 Boiler to Header (B middle)	Non-installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	83.5	507	432
	No.12 Boiler to Header (B middle)	10mm installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	82.3	490	775
	No.12 Boiler to Header (B middle)	20mm installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	90.9	611	403
	No.12 Boiler to Header (B middle)	40mm installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	92.5	634	486
	No.12 Boiler to Header (B middle)	Non-installation area	Installed	10/09/2014	273	150	0	0.573	Horizontal	32.4	0.0	78.2	496	425
	No.12 Boiler to Header (B middle)	10mm installation area	Installed	10/09/2014	273	150	10	0.593	Horizontal	32.4	0.0	59.2	260	415
	No.12 Boiler to Header (B middle)	20mm installation area	Installed	10/09/2014	273	150	20	0.613	Horizontal	32.4	0.0	54.8	211	335
	No.12 Boiler to Header (B middle)	40mm installation area	Installed	10/09/2014	273	150	40	0.653	Horizontal	32.4	0.0	49.5	154	208
	No.10 Boiler to Header (B Middle)	Non-installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	86.4	581	1063
	No.10 Boiler to Header (B Middle)	10mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	73.1	403	873
	No.10 Boiler to Header (B Middle)	20mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	75.1	428	590
	No.10 Boiler to Header (B Middle)	40mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	67.6	334	535
	No.10 Boiler to Header (B Middle)	Non-installation area	Installed	13/09/2014	273	150	0	0.573	Horizontal	28.5	0.0	86.9	656	931
	No.10 Boiler to Header (B Middle)	10mm installation area	Installed	13/09/2014	273	150	10	0.593	Horizontal	28.5	0.0	63.0	342	516
	No.10 Boiler to Header (B Middle)	20mm installation area	Installed	13/09/2014	273	150	20	0.613	Horizontal	28.5	0.0	56.8	270	303
	No.10 Boiler to Header (B Middle)	40mm installation area	Installed	13/09/2014	273	150	40	0.653	Horizontal	28.5	0.0	49.2	187	242
	No.13 Boiler to Header (B top)	Non-installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	73.7	312	776
	No.13 Boiler to Header (B top)	10mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	72.3	294	472
	No.13 Boiler to Header (B top)	20mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	72.7	299	619
	No.13 Boiler to Header (B top)	40mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	79.5	386	739
	No.13 Boiler to Header (B top)	Non-installation area	Installed	13/09/2014	273	150	0	0.573	Horizontal	39.1	0.0	70.9	333	512
	No.13 Boiler to Header (B top)	10mm installation area	Installed	13/09/2014	273	150	10	0.593	Horizontal	39.1	0.0	67.7	293	493
	No.13 Boiler to Header (B top)	20mm installation area	Installed	13/09/2014	273	150	20	0.613	Horizontal	39.1	0.0	65.8	270	344
	No.13 Boiler to Header (B top)	40mm installation area	Installed	13/09/2014	273	150	40	0.653	Horizontal	39.1	0.0	59.3	195	261
CHP4	Header Pipe	Non-installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	66.3	283	295
	Header Pipe	10mm installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	65.9	278	311
	Header Pipe	20mm installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	68.2	305	372
	Header Pipe	40mm installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	68.9	314	331
	Header Pipe	Non-installation area	Installed	12/09/2014	377	200	0	0.777	Horizontal	40.5	0.0	67.1	267	309
	Header Pipe	10mm installation area	Installed	12/09/2014	377	200	10	0.797	Horizontal	40.5	0.0	62.8	217	248
	Header Pipe	20mm installation area	Installed	12/09/2014	377	200	20	0.817	Horizontal	40.5	0.0	61.0	197	283
	Header Pipe	40mm installation area	Installed	12/09/2014	377	200	40	0.857	Horizontal	40.5	0.0	54.5	128	149
	No.3 Boiler to Header (B top)	Non-installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	71.5	294	298
	No.3 Boiler to Header (B top)	10mm installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	73.5	318	272
	No.3 Boiler to Header (B top)	20mm installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	75.1	338	371
	No.3 Boiler to Header (B top)	40mm installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	67.8	250	240
	No.3 Boiler to Header (B top)	Non-installation area	Installed	12/09/2014	377	200	0	0.777	Horizontal	39.9	0.0	71.2	321	248
	No.3 Boiler to Header (B top)	10mm installation area	Installed	12/09/2014	377	200	10	0.797	Horizontal	39.9	0.0	69.4	299	264
	No.3 Boiler to Header (B top)	20mm installation area	Installed	12/09/2014	377	200	20	0.817	Horizontal	39.9	0.0	64.9	246	290
	No.3 Boiler to Header (B top)	40mm installation area	Installed	12/09/2014	377	200	40	0.857	Horizontal	39.9	0.0	59.1	181	170
	No.5 Boiler to Header (B top)	Non-installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	64.8	260	388
	No.5 Boiler to Header (B top)	10mm installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	66.2	276	398
	No.5 Boiler to Header (B top)	20mm installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	66.2	276	314
	No.5 Boiler to Header (B top)	40mm installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	64.9	261	302
	No.5 Boiler to Header (B top)	Non-installation area	Installed	12/09/2014	377	200	0	0.777	Horizontal	35.4	0.0	63.8	278	459
	No.5 Boiler to Header (B top)	10mm installation area	Installed	12/09/2014	377	200	10	0.797	Horizontal	35.4	0.0	61.7	254	348
	No.5 Boiler to Header (B top)	20mm installation area	Installed	12/09/2014	377	200	20	0.817	Horizontal	35.4	0.0	59.4	228	295
	No.5 Boiler to Header (B top)	40mm installation area	Installed	12/09/2014	377	200	40	0.857	Horizontal	35.4	0.0	56.2	193	200

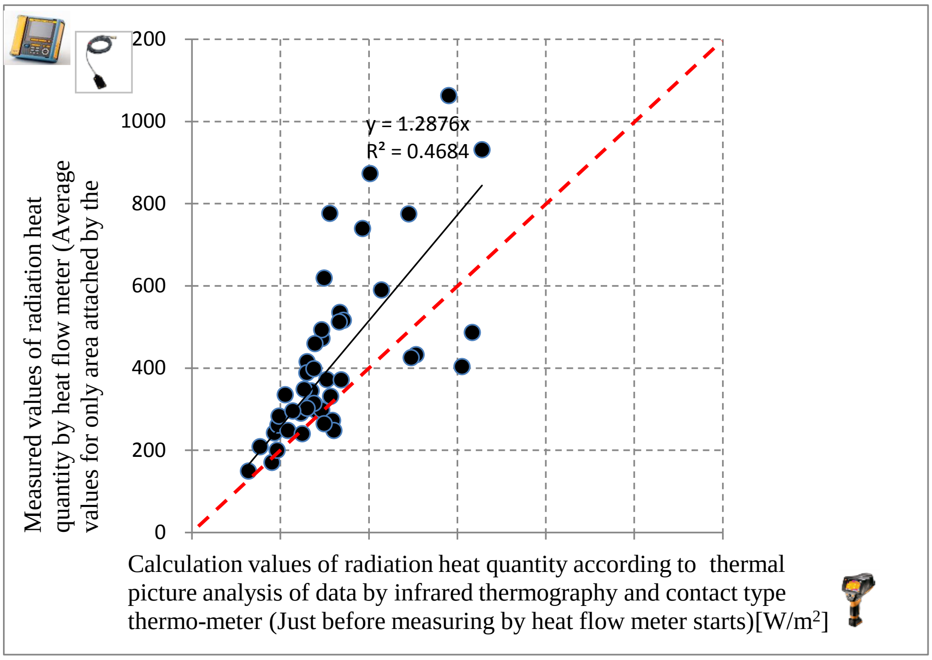


Figure AP2-2 Correlation chart between both values for radiation heat quantity identified by heat flow meter and infrared thermography

As Figure AP2-2 illustrates, values measured by heat flow meter are wholly a little higher than ones calculated based on measurement data by infrared thermography. As for correlation between both ones, it follows that the contributing rate is 0.4684 (the correlation coefficient is 0.6844.).

One could argue that this correlation is significant to a satisfactory extent although sample correlation coefficient is 0.368326 in case of in case sample size of 48 (n=48) and significance level of 1% (α=0.01).

Table AP2-2 Correlation coefficient r table[5]

[5] Values in the table are ones for correlation coefficient which are critical on the test based on t distribution in case of significance level: α (two-tailed probability) and degree of freedom of n–2 .

sample size	significance level: α (two-tailed probability)			
n	0.1	0.05	0.02	0.01
3	0.987688	0.996917	0.999507	0.999877
4	0.9	0.95	0.98	0.99
5	0.805384	0.878339	0.934333	0.958735
6	0.729299	0.811401	0.882194	0.9172
7	0.669439	0.754492	0.832874	0.874526
8	0.621489	0.706734	0.78872	0.834342
9	0.582206	0.666384	0.749776	0.797681
10	0.549357	0.631897	0.715459	0.764592
11	0.521404	0.602069	0.685095	0.734786
12	0.497265	0.575983	0.65807	0.707888
13	0.476156	0.552943	0.633863	0.683528
14	0.4575	0.532413	0.612047	0.661376
15	0.440861	0.513977	0.59227	0.641145
16	0.425902	0.497309	0.574245	0.622591
17	0.41236	0.482146	0.557737	0.605506
18	0.400027	0.468277	0.542548	0.589714
19	0.388733	0.455531	0.528517	0.575067
20	0.378341	0.443763	0.515505	0.561435
21	0.368737	0.432858	0.503397	0.548711
22	0.359827	0.422714	0.492094	0.5368
23	0.351531	0.413247	0.481512	0.52562
24	0.343783	0.404386	0.471579	0.515101
25	0.336524	0.39607	0.462231	0.505182
26	0.329705	0.388244	0.453413	0.495808
27	0.323283	0.380863	0.445078	0.486932
28	0.317223	0.373886	0.437184	0.478511
29	0.31149	0.367278	0.429693	0.470509
30	0.306057	0.361007	0.422572	0.462892
31	0.300898	0.355046	0.415792	0.455631
32	0.295991	0.34937	0.409327	0.448699
33	0.291316	0.343957	0.403153	0.442072
34	0.286856	0.338788	0.397249	0.435728
35	0.282594	0.333845	0.391596	0.429648
36	0.278517	0.329111	0.386177	0.423814
37	0.274611	0.324573	0.380976	0.418211
38	0.270864	0.320217	0.375979	0.412823
39	0.267267	0.316032	0.371173	0.407637
40	0.263809	0.312006	0.366546	0.402641
41	0.260482	0.308131	0.362087	0.397824
42	0.257278	0.304396	0.357787	0.393174
43	0.254189	0.300793	0.353636	0.388684
44	0.251209	0.297315	0.349626	0.384343
45	0.24833	0.293955	0.34575	0.380144
46	0.245549	0.290706	0.341999	0.37608
47	0.242859	0.287563	0.338367	0.372142
48	0.240255	0.284519	0.334848	0.368326
49	0.237734	0.28157	0.331437	0.364624
50	0.23529	0.278711	0.328128	0.361031

<u>Identification of representative value of reference radiation heat quantity (parameter fixed ex ante)</u>

Temperature distribution on the surface of the existing thermal insulation material at CHPs in Mongolia ranges in scope, because the content of asbestos in the existing thermal insulation material is considerably different with location and we can see many deterioration points on them.

Under these circumstances, infrared thermography is better for the measurement, however it cannot measure.

Furthermore, values measured by heat flow meter are wholly a little higher than calculated based on measurement data by infrared thermography. So, data of thermal diagnosis (in FS of FY2013) is applied to identify the representative value for reference radiation heat quantity (before thermal insulation installation) in conservative manner.

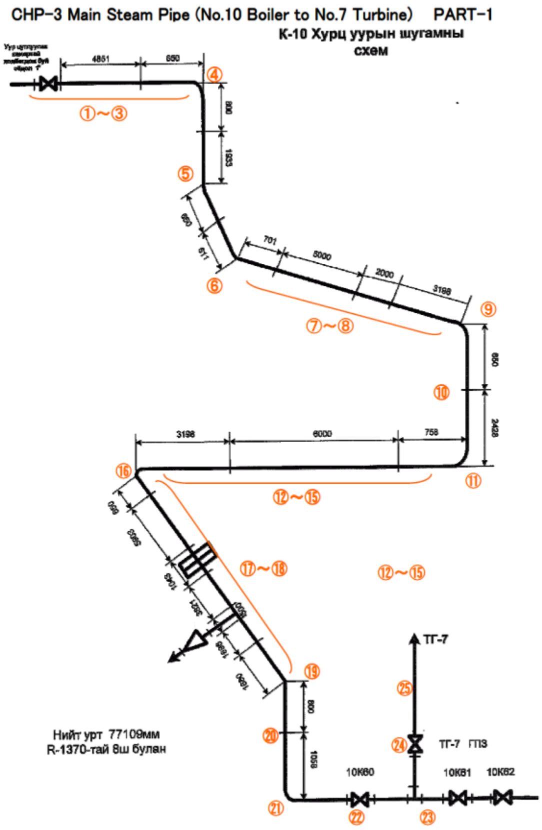
Study contents in thermal diagnosis are as follows;

Table AP2-4.1 Study contents for thermal diagnosis in FS of FY2013

	CHP3 high pressure unit	CHP4
Measurement date	15, 16 October 2013	21, 23 October 2013
Measuring point:	56 points on main steam pipe linage between No.10 boiler outlet and No.7 turbine inlet (Please refer Figure AP2-3.1.)	58 points on main steam pipe linage between No.3 boiler outlet and No.2 turbine inlet (Please refer Figure AP2-3.2.)
Measuring parameter	•Surface temperature •Ambient temperature •Around wind velocity	

Table AP2-4.2 Information of measuring equipment used in thermal diagnosis

Equipment	Item	Specification
Infrared thermography	Manufacture, type	Nippon Avionics Co., Ltd., InfReC R300
	Temperature range	-40°C～500°C
	Temperature resolution	0.03°C at 30°C
	Temperature precision	±1°C
	Frame rate	60Hz
	Pixel numbers	640×480pixels／320×240pixels
	View angle	44°×34° (wide-angle lens attached)
	Work environments	-15°C～50°C, not excess of 90%RH
Contact-type thermometer	Manufacture, type	Anritsu Corporation, HFT-50
	Temperature range	-99.9°C～499.9°C
	Temperature resolution	0.1°C
	Temperature precision	0°C and above : ±(indicated value×0.05% +0.2)°C, less than 0°C : ±0.5°C
Digital multi-meter	Manufacture, type	FUSO Co., LM8000
	Wind speed range	0.4～30m/s
	Wind speed resolution	indicated resolution 0.1m/s
	Wind speed precision	±3%F.S.



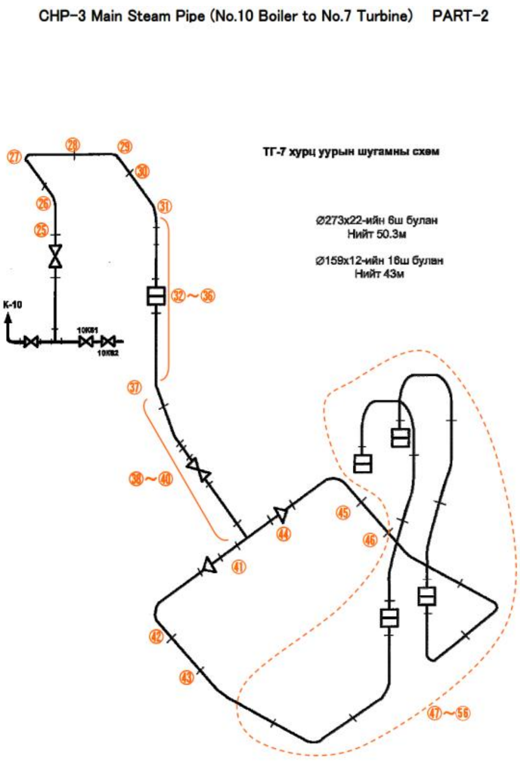


Figure AP2-3.1 Measuring points for thermal diagnosis in FS of FY2013 (Main steam pipe linage between No.10 boiler outlet and No.7 turbine inlet at CHP3 high pressure unit)

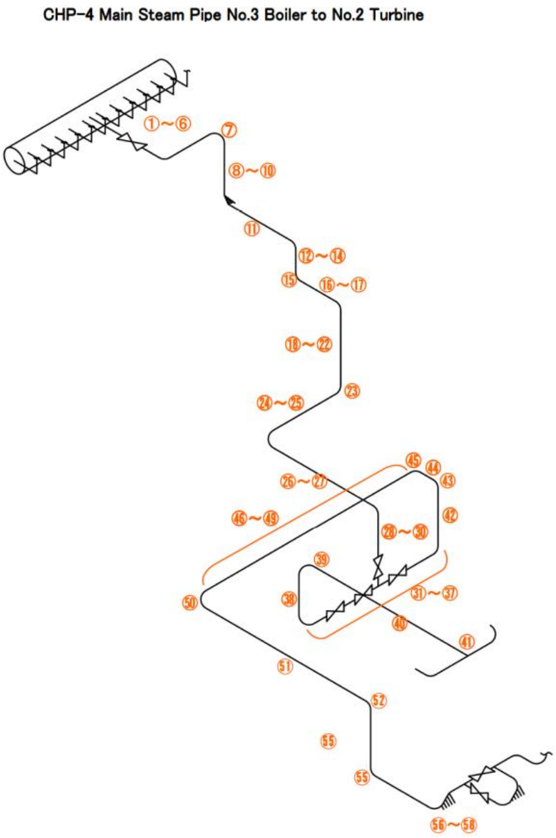


Figure AP2-3.2 Measuring points for thermal diagnosis in FS of FY2013 (Main steam pipe linage between No.3 boiler outlet and No.2 turbine inlet at CHP4)

The thermal diagnosis test for CHP3 was performed on 15 and 16 October in 2013. And the one for CHP4 was performed on 21 and 23 in October 2013. The season is seemed to close to be the annually-averaged one. According to the result of these tests, there was no measuring point for over 45 °C around main steam pipes.

Then the study was performed on 8-16 September in 2014. The season is seemed to be warmer than the annually-averaged one. According to the result of the study, ambient temperatures around main steam pipe for Boiler top positions where were most hottest within the CHP hovered around 45 °C.

Furthermore, according to data indoor working conditions at CHP3 and CHP4, there was no measuring point over 45 °C for annual average ambient temperatures around main steam pipes. So, for the purpose of identifying reference radiation heat quantity in conservative manner, 45°C is applied to the conservative value for ambient temperature around main steam pipe at CHP3 and CHP4.

The following values are shown in Table AP2-5.1 and Table AP2-5.2.
For each of CHP3 and CHP4;

- Calculation values of radiation heat quantity according to thermographic image analysis for data measured by infrared thermography for thermal diagnosis in FS of FY2013
- Conservative values of radiation heat quantity adjusted as ambient temperature of 45°C

The results of the following analyses are shown in Figure AP2-4.1 and Figure AP2-4.2.
For each of CHP3 and CHP4;

- Arrange all (conservative) values for radiation heat quantity in ascending order.
- Calculate the average value of all (conservative) values.
- Calculate the average value within 95% confidence interval
- Calculate the average value within 95% confidence interval (between θ-1.96σ and θ+1.96σ)
- Calculate the average value up to the upper limit value of 95% confidence interval (θ+1.96σ)

Table AP2-5.1 Calculation values of radiation heat quantity according to thermographic image analysis for data measured by infrared thermography for thermal diagnosis in FS of FY2013 and conservative value of radiation heat quantity adjusted by conservative ambient temperature (CHP3 high pressure unit)

No.	Location	Thermographic Measurement: Ambient Temp	Wind velocity	Surface Temp.: Max.	Min.	Ave.	Pipe direction	Emissivity	Objective pipe: Outside diameter of the existing pipe	Thickness covered by the existing thermal insulation material	Outside diameter including the existing thermal insulation material	Radiation heat quantity: for radiative part	for convective part: In case of vertical pipe	In case of horizontal pipe	Total	Internal tenp. (Steam temp.in the pipe)	Ambient temp. set for Conservativeness	Adjusted radiation heat quantity: Radiation heat quantity adjusted by conservative ambient temp.	Data up to the upper limit value of 95% confidence interval	Data within 95% confidence interval
		°C	m/s	°C				-	mm	mm	m	W/m²				°C	°C	W/m²		
1	No.10 Boiler to Header Pipe	38.1	0.0	271.1	54.0	89.7	Horizontal	0.9	273	150	0.573	406	354	189	595	531	45.0	586	586	586
2	No.10 Boiler to Header Pipe	38.1	0.0	121.6	64.6	77.5	Horizontal	0.9	273	150	0.573	293	253	135	428	531	45.0	422	422	422
3	No.10 Boiler to Header Pipe	38.1	0.0	95.2	59.3	72.7	Horizontal	0.9	273	150	0.573	251	215	115	366	531	45.0	361	361	361
4	No.10 Boiler to Header Pipe	38.1	0.0	270.4	62.9	88.7	Horizontal	0.9	273	150	0.573	396	345	185	581	531	45.0	572	572	572
5	No.10 Boiler to Header Pipe	38.1	0.0	166.7	40.4	102.5	Vertical	0.9	273	150	0.573	537	467	250	1004	531	45.0	990	990	990
6	No.10 Boiler to Header Pipe	36.1	0.0	187.7	54.1	105.8	Horizontal	0.9	273	150	0.573	586	516	275	861	531	45.0	846	846	846
7	No.10 Boiler to Header Pipe	36.1	0.0	188.1	79.8	104.1	Horizontal	0.9	273	150	0.573	567	500	267	834	531	45.0	819	819	819
8	No.10 Boiler to Header Pipe	36.1	0.0	118.5	62.2	79.7	Horizontal	0.9	273	150	0.573	324	287	153	478	531	45.0	469	469	469
9	No.10 Boiler to Header Pipe	35.0	0.0	204.3	56.2	95.0	Horizontal	0.9	273	150	0.573	477	427	228	706	531	45.0	691	691	691
10	No.10 Boiler to Header Pipe	35.0	0.0	179.3	62.1	98.8	Vertical	0.9	273	150	0.573	517	462	247	978	531	45.0	958	958	958
11	No.10 Boiler to Header Pipe	35.0	0.0	169.8	70.0	105.3	Horizontal	0.9	273	150	0.573	587	521	278	865	531	45.0	848	848	848
12	No.10 Boiler to Header Pipe	35.0	0.0	215.6	69.5	108.6	Horizontal	0.9	273	150	0.573	624	552	295	919	531	45.0	900	900	900
13	No.10 Boiler to Header Pipe	35.0	0.0	224.9	67.3	88.2	Horizontal	0.9	273	150	0.573	410	368	197	606	531	45.0	594	594	594
14	No.10 Boiler to Header Pipe	35.0	0.0	201.8	68.8	92.5	Horizontal	0.9	273	150	0.573	452	405	217	669	531	45.0	655	655	655
15	No.10 Boiler to Header Pipe	35.0	0.0	146.4	69.3	92.7	Horizontal	0.9	273	150	0.573	454	407	218	672	531	45.0	658	658	658
16	No.10 Boiler to Header Pipe	35.0	0.0	374.1	66.3	108.4	Horizontal	0.9	273	150	0.573	621	550	294	915	531	45.0	897	897	897
17	No.10 Boiler to Header Pipe	35.0	0.0	100.3	50.2	69.4	Horizontal	0.9	273	150	0.573	242	213	114	356	531	45.0	349	349	349
18	No.10 Boiler to Header Pipe	35.0	0.0	161.5	77.9	108.9	Horizontal	0.9	273	150	0.573	627	555	296	923	531	45.0	905	905	905
19	No.10 Boiler to Header Pipe	35.0	0.0	210.4	87.0	117.2	Horizontal	0.9	273	150	0.573	725	634	339	1063	531	45.0	1042	1042	1042
20	No.10 Boiler to Header Pipe	35.0	0.0	155.1	91.1	109.5	Vertical	0.9	273	150	0.573	634	560	299	1194	531	45.0	1170		
21	No.10 Boiler to Header Pipe	35.0	0.0	168.0	85.5	110.9	Horizontal	0.9	273	150	0.573	650	574	306	956	531	45.0	937	937	937
22	No.10 Boiler to Header Pipe	35.0	0.0	342.9	47.3	105.0	Horizontal	0.9	273	150	0.573	583	518	277	860	531	45.0	843	843	843
23	No.10 Boiler to Header Pipe	35.0	0.0	194.1	60.2	92.2	Horizontal	0.9	273	150	0.573	449	403	215	664	531	45.0	651	651	651
24	Header Pipe to No.7 Turbine	35.0	0.0	253.5	70.5	102.6	Vertical	0.9	159	150	0.459	557	496	280	1053	528	45.0	1032	1032	1032
25	Header Pipe to No.7 Turbine	35.0	0.0	262.5	56.8	88.7	Vertical	0.9	159	150	0.459	415	372	210	787	528	45.0	771	771	771
26	Header Pipe to No.7 Turbine	35.0	0.0	431.4	47.5	84.1	Horizontal	0.9	159	150	0.459	371	333	188	559	528	45.0	548	548	548
27	Header Pipe to No.7 Turbine	35.0	0.0	118.5	56.4	81.6	Horizontal	0.9	159	150	0.459	348	312	176	524	528	45.0	513	513	513
28	Header Pipe to No.7 Turbine	35.0	0.0	135.1	49.9	82.5	Horizontal	0.9	159	150	0.459	356	319	180	537	528	45.0	526	526	526
29	Header Pipe to No.7 Turbine	35.0	0.0	159.8	56.1	83.5	Horizontal	0.9	159	150	0.459	366	328	185	551	528	45.0	539	539	539
30	Header Pipe to No.7 Turbine	35.0	0.0	186.4	62.0	85.3	Horizontal	0.9	159	150	0.459	382	343	194	576	528	45.0	564	564	564
31	Header Pipe to No.7 Turbine	35.0	0.0	148.4	46.2	74.7	Horizontal	0.9	159	150	0.459	287	255	144	431	528	45.0	422	422	422
32	Header Pipe to No.7 Turbine	35.0	0.0	234.4	69.3	89.3	Vertical	0.9	159	150	0.459	421	377	213	798	528	45.0	782	782	782
33	Header Pipe to No.7 Turbine	26.0	0.0	115.2	51.3	71.0	Vertical	0.9	159	150	0.459	307	298	169	606	528	45.0	583	583	583
34	Header Pipe to No.7 Turbine	26.0	0.0	140.6	40.9	62.8	Vertical	0.9	159	150	0.459	241	232	131	473	528	45.0	455	455	455
35	Header Pipe to No.7 Turbine	26.0	0.0	87.3	54.7	65.8	Vertical	0.9	159	150	0.459	265	256	145	521	528	45.0	501	501	501
36	Header Pipe to No.7 Turbine	26.0	0.0	87.5	53.1	69.3	Vertical	0.9	159	150	0.459	293	284	161	577	528	45.0	556	556	556
37	Header Pipe to No.7 Turbine	26.0	0.0	121.1	44.4	76.7	Horizontal	0.9	159	150	0.459	356	346	196	551	528	45.0	531	531	531
38	Header Pipe to No.7 Turbine	26.0	0.0	146.0	53.1	75.0	Horizontal	0.9	159	150	0.459	341	332	187	528	528	45.0	508	508	508
39	Header Pipe to No.7 Turbine	26.0	0.0	130.1	58.8	84.8	Horizontal	0.9	159	150	0.459	429	417	235	664	528	45.0	639	639	639
40	Header Pipe to No.7 Turbine	26.0	0.0	192.4	46.7	89.5	Horizontal	0.9	159	150	0.459	474	459	259	733	528	45.0	705	705	705
41	Header Pipe to No.7 Turbine	26.0	0.0	115.8	36.3	71.2	Horizontal	0.9	159	150	0.459	309	300	169	478	528	45.0	460	460	460
42	Header Pipe to No.7 Turbine	26.0	0.0	97.9	32.0	52.2	Horizontal	0.9	159	150	0.459	163	152	86	249	528	45.0	239	239	239
43	Header Pipe to No.7 Turbine	26.0	0.0	103.7	37.4	56.3	Horizontal	0.9	159	150	0.459	192	182	103	295	528	45.0	284	284	284
44	Header Pipe to No.7 Turbine	26.0	0.0	265.9	31.2	60.1	Horizontal	0.9	159	150	0.459	221	211	119	340	528	45.0	327	327	327
45	Header Pipe to No.7 Turbine	26.0	0.0	101.5	38.5	59.1	Horizontal	0.9	159	150	0.459	213	203	115	328	528	45.0	316	316	316
46	Header Pipe to No.7 Turbine	26.0	0.0	94.9	42.2	63.0	Horizontal	0.9	159	150	0.459	243	234	132	375	528	45.0	361	361	361
47	Header Pipe to No.7 Turbine	26.0	0.0	76.3	44.7	58.4	Vertical	0.9	159	150	0.459	208	198	112	406	528	45.0	390	390	390
48	Header Pipe to No.7 Turbine	26.0	0.0	220.2	36.7	80.8	Vertical	0.9	159	150	0.459	392	382	216	774	528	45.0	745	745	745
49	Header Pipe to No.7 Turbine	26.0	0.0	361.4	39.7	87.2	Horizontal	0.9	159	150	0.459	452	438	247	699	528	45.0	673	673	673
50	Header Pipe to No.7 Turbine	26.0	0.0	447.6	62.4	140.2	Horizontal	0.9	159	150	0.459	1081	956	540	1621	528	45.0	1559		
51	Header Pipe to No.7 Turbine	26.0	0.0	280.6	50.1	115.2	Horizontal	0.9	159	150	0.459	752	702	396	1148	528	45.0	1105	1105	1105
52	Header Pipe to No.7 Turbine	26.0	0.0	442.9	51.0	100.9	Horizontal	0.9	159	150	0.459	590	564	319	909	528	45.0	874	874	874
53	Header Pipe to No.7 Turbine	23.0	0.0	134.3	52.5	77.7	Vertical	0.9	159	150	0.459	381	381	215	762	528	45.0	728	728	728
54	Header Pipe to No.7 Turbine	23.0	0.0	171.4	48.5	75.7	Vertical	0.9	159	150	0.459	363	363	205	727	528	45.0	695	695	695
55	Header Pipe to No.7 Turbine	23.0	0.0	163.9	50.0	77.5	Vertical	0.9	159	150	0.459	379	379	214	758	528	45.0	725	725	725
56	Header Pipe to No.7 Turbine	23.0	0.0	193.2	37.9	84.7	Vertical	0.9	159	150	0.459	444	443	250	887	528	45.0	848	848	848
	Average	31.3	0.0	-	-	86.6														

Data No.	n	56
Average	q	691.4
Standard deviation	s_0	258.7
The lower limit value of 95% confidence interval	$q-1.96*s_0$	184.4
The upper limit value of 95% confidence interval	$q+1.96*s_0$	1198.4

Data No.	56	54	54
Average	672.7	647	647
Standard deviation	251.8		
The lower limit value of 95% confidence interval	179.1		
The upper limit value of 95% confidence interval	1166.3		

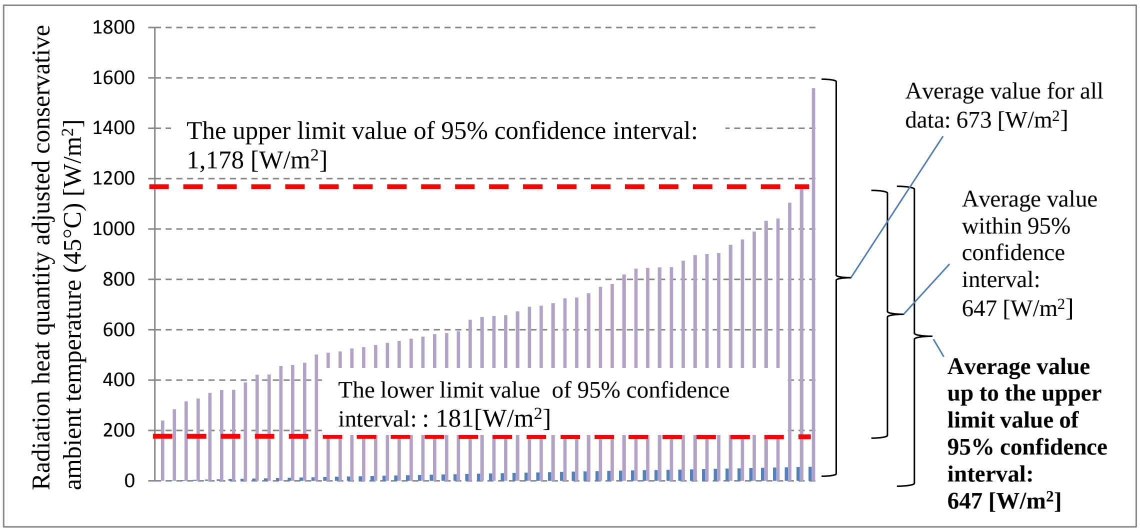


Figure AP2-4.1 Sorting figure for conservative radiation heat quantities (CHP3 high pressure unit)

Table AP2-5.2 Calculation values of radiation heat quantity according to thermographic image analysis for data measured by infrared thermography for thermal diagnosis in FS of FY2013 and conservative value of radiation heat quantity adjusted by conservative ambient temperature (CHP4)

No.	Location	Thermographic Measurement: Ambient Temp	Thermographic Measurement: Wind speed	Surface Temp. Max.	Surface Temp. Min.	Surface Temp. Ave.	Pipe direction	Emissivity	Objective pipe: Outside diameter of the existing pipe	Objective pipe: Thickness covered by the existing thermal insulation material	Objective pipe: Outside diameter including the existing thermal insulation material	Radiation heat quantity: for radiative part	Radiation heat quantity for convective part: In case of vertival pipe	Radiation heat quantity for convective part: In case of horizontal pipe	Radiation heat quantity: Total	Internal tenp. (Steam temp.in the pipe)	Ambient temp. set for Conservativeness	Adjusted radiation heat quantity: Radiation heat quantity adjusted by conservative ambient temp.	Adjusted radiation heat quantity: Data up to the upper limit value of 95% confidence interval	Adjusted radiation heat quantity: Data within 95% confidence interval
		°C	m/s	°C				-	mm	mm	m	W/m²				°C	°C	W/m²		
1	Main steam pipe No.3 boiler to header	33.1	0.0	109.3	59.0	78.2	Horizontal	0.9	377	200	0.777	329	299	148	477	553	45.0	466	466	466
2	Main steam pipe No.3 boiler to header	33.1	0.0	196.6	53.3	70.8	Horizontal	0.9	377	200	0.777	265	239	118	384	553	45.0	375	375	375
3	Main steam pipe No.3 boiler to header	33.1	0.0	78.3	55.6	62.2	Horizontal	0.9	377	200	0.777	197	173	86	282	553	45.0	276	276	276
4	Main steam pipe No.3 boiler to header	33.1	0.0	93.3	56.2	66.1	Horizontal	0.9	377	200	0.777	227	202	100	327	553	45.0	320	320	320
5	Main steam pipe No.3 boiler to header	33.1	0.0	101.5	57.0	73.7	Horizontal	0.9	377	200	0.777	290	262	130	420	553	45.0	410	410	410
6	Main steam pipe No.3 boiler to header	33.1	0.0	165.3	50.7	73.4	Horizontal	0.9	377	200	0.777	287	260	129	416	553	45.0	406	406	406
7	Main steam pipe No.3 boiler to header	33.1	0.0	373.1	66.6	150.7	Horizontal	0.9	377	200	0.777	1198	991	491	1689	553	45.0	1650		
8	Main steam pipe No.3 boiler to header	33.1	0.0	96.7	53.0	68.2	Vertical	0.9	377	200	0.777	244	219	108	463	553	45.0	452	452	452
9	Main steam pipe No.3 boiler to header	33.1	0.0	128.8	44.4	63.4	Vertical	0.9	377	200	0.777	206	182	90	388	553	45.0	379	379	379
10	Main steam pipe No.3 boiler to header	31.6	0.0	75.7	50.3	59.5	Vertical	0.9	377	200	0.777	185	164	81	349	553	45.0	340	340	340
11	Main steam pipe No.3 boiler to header	31.6	0.0	192.1	44.1	59.2	Horizontal	0.9	377	200	0.777	182	162	80	263	553	45.0	256	256	256
12	Main steam pipe No.3 boiler to header	34.3	0.0	104.4	46.5	75.9	Horizontal	0.9	377	200	0.777	302	270	134	435	553	45.0	426	426	426
13	Main steam pipe No.3 boiler to header	34.3	0.0	161.3	48.4	62.9	Horizontal	0.9	377	200	0.777	195	169	84	279	553	45.0	273	273	273
14	Main steam pipe No.3 boiler to header	34.3	0.0	81.7	43.8	53.7	Horizontal	0.9	377	200	0.777	126	104	52	178	553	45.0	174	174	174
15	Main steam pipe No.3 boiler to header	34.3	0.0	327.3	34.0	58.4	Vertical	0.9	377	200	0.777	161	137	68	297	553	45.0	291	291	291
16	Main steam pipe No.3 boiler to header	34.3	0.0	63.7	38.8	52.5	Horizontal	0.9	377	200	0.777	118	96	48	166	553	45.0	162	162	162
17	Main steam pipe No.3 boiler to header	34.3	0.0	93.1	41.6	57.0	Horizontal	0.9	377	200	0.777	150	127	63	213	553	45.0	209	209	209
18	Main steam pipe No.3 boiler to header	33.2	0.0	385.3	40.3	59.6	Vertical	0.9	377	200	0.777	176	153	76	329	553	45.0	322	322	322
19	Main steam pipe No.3 boiler to header	33.2	0.0	54.0	44.3	49.2	Vertical	0.9	377	200	0.777	102	82	41	183	553	45.0	179	179	179
20	Main steam pipe No.3 boiler to header	33.2	0.0	179.0	42.8	63.1	Vertical	0.9	377	200	0.777	203	179	89	382	553	45.0	373	373	373
21	Main steam pipe No.3 boiler to header	33.2	0.0	77.7	42.1	58.6	Vertical	0.9	377	200	0.777	169	146	72	315	553	45.0	307	307	307
22	Main steam pipe No.3 boiler to header	33.2	0.0	109.8	50.0	57.9	Vertical	0.9	377	200	0.777	163	141	70	304	553	45.0	298	298	298
23	Main steam pipe No.3 boiler to header	33.2	0.0	234.1	38.1	72.3	Vertical	0.9	377	200	0.777	277	250	124	528	553	45.0	516	516	516
24	Main steam pipe No.3 boiler to header	33.2	0.0	219.2	52.4	69.4	Horizontal	0.9	377	200	0.777	253	227	113	366	553	45.0	357	357	357
25	Main steam pipe No.3 boiler to header	33.2	0.0	84.7	53.0	63.9	Horizontal	0.9	377	200	0.777	209	185	92	301	553	45.0	294	294	294
26	Main steam pipe No.3 boiler to header	33.2	0.0	338.6	64.5	89.2	Horizontal	0.9	377	200	0.777	430	392	194	624	553	45.0	610	610	610
27	Main steam pipe No.3 boiler to header	33.2	0.0	91.4	59.5	83.4	Horizontal	0.9	377	200	0.777	375	342	169	545	553	45.0	532	532	532
28	Main steam pipe No.3 boiler to header	33.2	0.0	318.8	68.0	158.6	Horizontal	0.9	377	200	0.777	1324	1074	532	1856	553	45.0	1813		
29	Main steam pipe No.3 boiler to header	33.2	0.0	300.2	77.7	173.0	Vertical	0.9	377	200	0.777	1572	1231	609	2803	553	45.0	2739		
30	Main steam pipe No.3 boiler to header	33.2	0.0	331.7	79.1	124.5	Vertical	0.9	377	200	0.777	826	722	358	1549	553	45.0	1514		
31	Main steam pipe No.3 boiler to header	33.2	0.0	135.0	42.2	70.4	Horizontal	0.9	377	200	0.777	261	235	116	378	553	45.0	369	369	369
32	Main steam pipe No.3 boiler to header	33.2	0.0	106.6	49.6	69.7	Horizontal	0.9	377	200	0.777	256	230	114	369	553	45.0	361	361	361
33	Main steam pipe No.3 boiler to header	33.2	0.0	85.1	53.4	69.8	Horizontal	0.9	377	200	0.777	256	230	114	371	553	45.0	362	362	362
34	Main steam pipe No.3 boiler to header	33.2	0.0	109.7	50.2	71.1	Horizontal	0.9	377	200	0.777	267	241	119	386	553	45.0	378	378	378
35	Main steam pipe No.3 boiler to header	33.2	0.0	292.2	57.6	78.8	Horizontal	0.9	377	200	0.777	334	303	150	484	553	45.0	473	473	473
36	Main steam pipe header to No.2 turbine	33.2	0.0	201.5	47.0	74.0	Horizontal	0.9	377	200	0.777	292	264	131	422	549	45.0	413	413	413
37	Main steam pipe header to No.2 turbine	33.2	0.0	100.1	54.9	68.3	Vertical	0.9	377	200	0.777	244	219	108	463	549	45.0	452	452	452
38	Main steam pipe header to No.2 turbine	33.2	0.0	76.5	50.5	61.8	Vertical	0.9	377	200	0.777	193	169	84	362	549	45.0	354	354	354
39	Main steam pipe header to No.2 turbine	33.2	0.0	101.1	48.4	61.3	Horizontal	0.9	377	200	0.777	189	166	82	271	549	45.0	265	265	265
40	Main steam pipe header to No.2 turbine	33.2	0.0	123.6	51.9	60.5	Horizontal	0.9	377	200	0.777	183	160	79	262	549	45.0	256	256	256
41	Main steam pipe header to No.2 turbine	33.2	0.0	99.7	36.9	54.1	Horizontal	0.9	377	200	0.777	136	114	57	192	549	45.0	188	188	188
42	Main steam pipe header to No.2 turbine	33.2	0.0	254.9	52.0	93.7	Vertical	0.9	377	200	0.777	475	432	214	907	549	45.0	886	886	886
43	Main steam pipe header to No.2 turbine	33.2	0.0	108.5	54.5	69.7	Vertical	0.9	377	200	0.777	256	230	114	485	549	45.0	474	474	474
44	Main steam pipe header to No.2 turbine	33.2	0.0	144.6	45.7	68.1	Horizontal	0.9	377	200	0.777	243	217	108	350	549	45.0	342	342	342
45	Main steam pipe header to No.2 turbine	33.2	0.0	104.9	57.5	71.2	Horizontal	0.9	377	200	0.777	268	242	120	388	549	45.0	379	379	379
46	Main steam pipe header to No.2 turbine	33.2	0.0	105.1	41.8	68.9	Horizontal	0.9	377	200	0.777	249	223	111	360	549	45.0	351	351	351
47	Main steam pipe header to No.2 turbine	33.2	0.0	94.0	51.4	64.6	Horizontal	0.9	377	200	0.777	215	190	94	309	549	45.0	302	302	302
48	Main steam pipe header to No.2 turbine	33.2	0.0	199.7	40.6	58.5	Horizontal	0.9	377	200	0.777	168	145	72	240	549	45.0	234	234	234
49	Main steam pipe header to No.2 turbine	33.2	0.0	144.7	43.9	66.6	Horizontal	0.9	377	200	0.777	230	206	102	332	549	45.0	325	325	325
50	Main steam pipe header to No.2 turbine	33.2	0.0	123.3	49.5	78.7	Horizontal	0.9	377	200	0.777	333	303	150	482	549	45.0	471	471	471
51	Main steam pipe header to No.2 turbine	33.2	0.0	103.7	64.7	79.5	Horizontal	0.9	377	200	0.777	340	309	153	493	549	45.0	482	482	482
52	Main steam pipe header to No.2 turbine	33.2	0.0	168.2	60.3	78.0	Vertical	0.9	377	200	0.777	326	297	147	623	549	45.0	609	609	609
53	Main steam pipe header to No.2 turbine	33.2	0.0	469.3	54.5	101.6	Vertical	0.9	377	200	0.777	557	504	249	1061	549	45.0	1036	1036	1036
54	Main steam pipe header to No.2 turbine	33.2	0.0	85.3	55.5	65.5	Vertical	0.9	377	200	0.777	222	197	98	419	549	45.0	409	409	409
55	Main steam pipe header to No.2 turbine	33.2	0.0	169.1	42.4	73.5	Vertical	0.9	377	200	0.777	287	260	129	547	549	45.0	535	535	535
56	Main steam pipe header to No.2 turbine	33.2	0.0	161.3	49.5	68.0	Horizontal	0.9	377	200	0.777	242	216	107	349	549	45.0	341	341	341
57	Main steam pipe header to No.2 turbine	33.2	0.0	105.3	51.3	70.6	Horizontal	0.9	377	200	0.777	263	237	117	380	549	45.0	372	372	372
58	Main steam pipe header to No.2 turbine	33.2	0.0	140.5	53.3	66.3	Horizontal	0.9	377	200	0.777	228	203	101	329	549	45.0	321	321	321
	Average	33.2	0.0	160.0	51.1	74.0														

Data No.	n	58
Average	q	502.1
Standard deviation	s_0	447.0
The lower limit value of 95% confidence interval	$q-1.96*s_0$	-373.9
The upper limit value of 95% confidence interval	$q+1.96*s_0$	1378.2

Data No.	58	52	52
Average	490.7	383	383
Standard deviation	436.8		
The lower limit value of 95% confidence interval	-365.4		
The upper limit value of 95% confidence interval	1346.8		

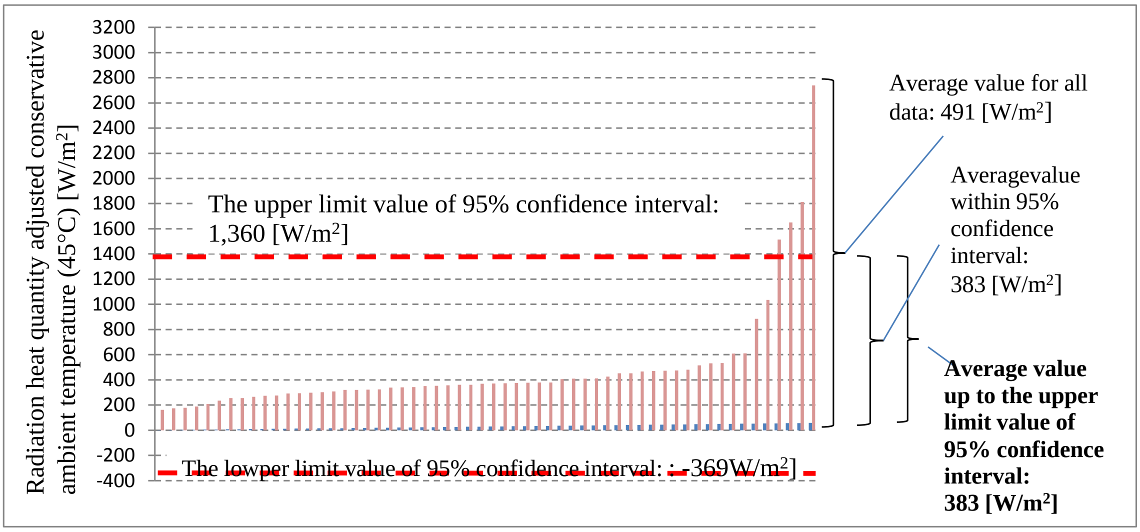


Figure AP2-4.2 Sorting figure for conservative radiation heat quantities (CHP4)

For each CHP3 and CHP4, the average value up to the upper limit value of 95% confidence interval is applied to the representative value for reference radiation heat quantity (parameter fixed ex ante) in conservative manner.

Table AP2-6 The representative value for reference radiation heat quantity qR_{RE} (parameter fixed ex ante)

Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage at CHP3 high pressure unit	$qR_{RE,CHP3\ hp}$	647	W/m^2
Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage at CHP4	$qR_{RE,CHP4}$	383	W/m^2

Identification of representative value of initial thermal insulation efficiency of the project thermal insulation material (parameter fixed ex ante)

As for thermographic image analysis of data measured by infrared thermography and contact type thermo-meter at 6 sampling installation areas of project thermal insulation material, pixels for the total area within the main steam pipe are extracted for each of 4 positions (1 position for non-installation and 3 installation positions for thickness of 10mm, 20mm and 40mm) in both of the case without installation and the one with installation.
Then, the average surface temperatures for the extracted pixels was calculated and converted to the radiation heat quantity from the extracted area based on equation JIS A9501.

In case of comparing radiation heat quantity between measurement value by heat flow meter and calculation value based on data according to thermographic image analysis by infrared thermography, pixels for only area attached by the heat flow sensor were extracted. While on the other hand, pixels for the total area within the main steam pipe are extracted in this case. Because data analysis targeted for wide area is better for the purpose of evaluating thermal insulation efficiency.

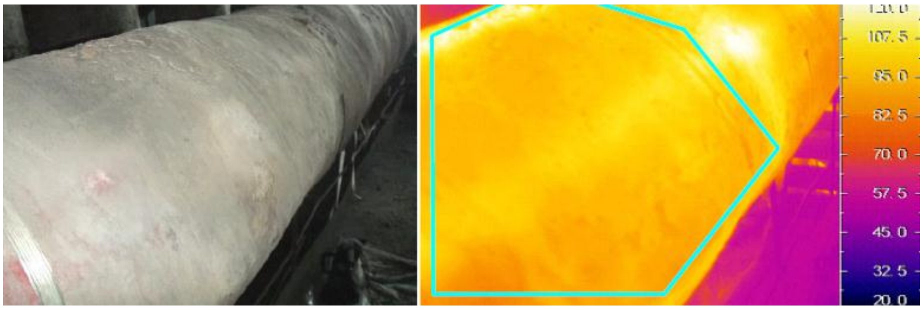


Figure AP2-5.1. Example of thermographic image pixels extracted for the total area within the main steam pipe without installation of project thermal insulation material

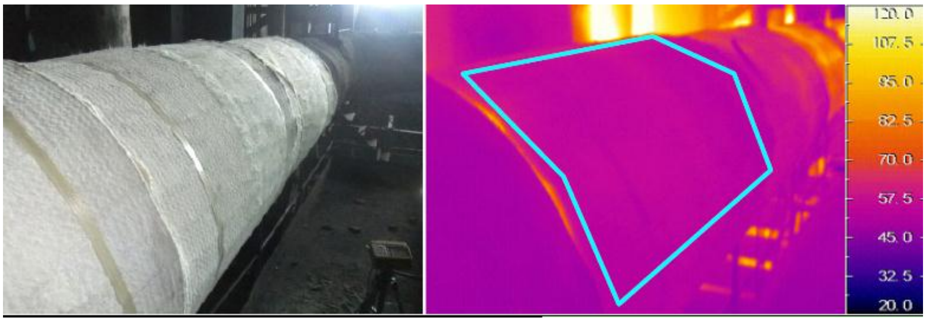


Figure AP2-5.2 Example of thermographic images pixels extracted for the total area within the main steam pipe with installation of project thermal insulation material

As already mentioned in Appendix 1, measurements by infrared thermography were performed with and without installation of the project thermal insulation material at same positions of each area.

At each area,
•Radiation heat quantities from 4 positions in status without installation of project thermal insulation material are assumed as $q_{0,unins}$, $q_{1,unins}$, $q_{2,unins}$ and $q_{4,unins}$
•Radiation heat quantities from 4 positions in status without installation of project thermal insulation material are assumed as $q_{0,ins}$, $q_{1,ins}$, $q_{2,ins}$ and $q_{4,ins}$
as Table AP2-7, Figure AP2-6.1 and Figure AP2-6.2 show;

Table AP2-7 Assumed values for radiation heat quantity

	Without installation of project thermal insulation material	With installation of project thermal insulation material
Radiation heat quantity from non-installation position [W/m^2]	$q_{0,unins}$	$q_{0,ins}$
Radiation heat quantity from installation position for thickness of 10mm [W/m^2]	$q_{1,unins}$	$q_{1,ins}$
Radiation heat quantity from installation position for thickness of 20mm [W/m^2]	$q_{2,unins}$	$q_{2,ins}$
Radiation heat quantity from installation position for thickness of 40mm [W/m^2]	$q_{4,unins}$	$q_{4,ins}$

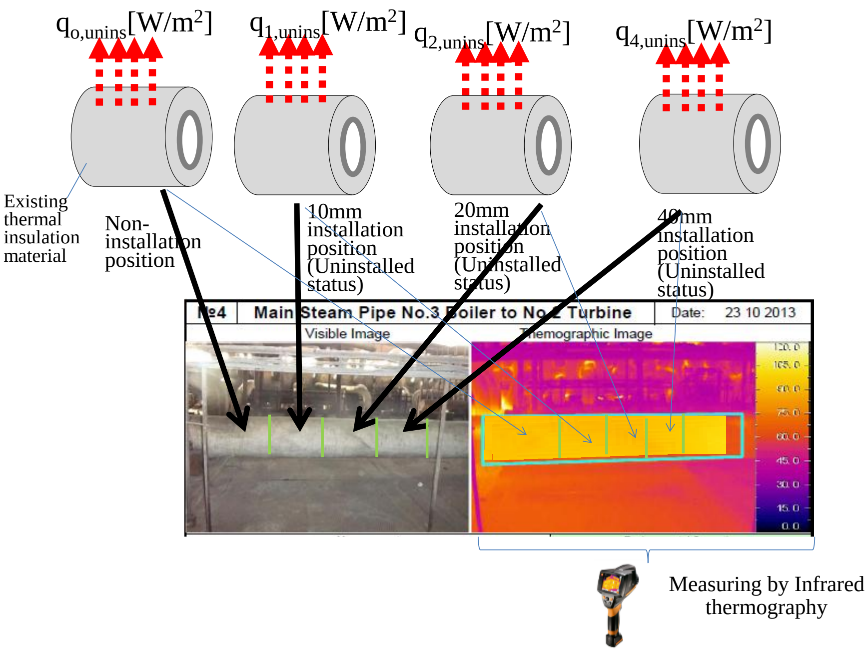


Figure AP2-6.1 Imaging figure of radiation heat quantity without sampling installation of the project thermal insulation material at each area

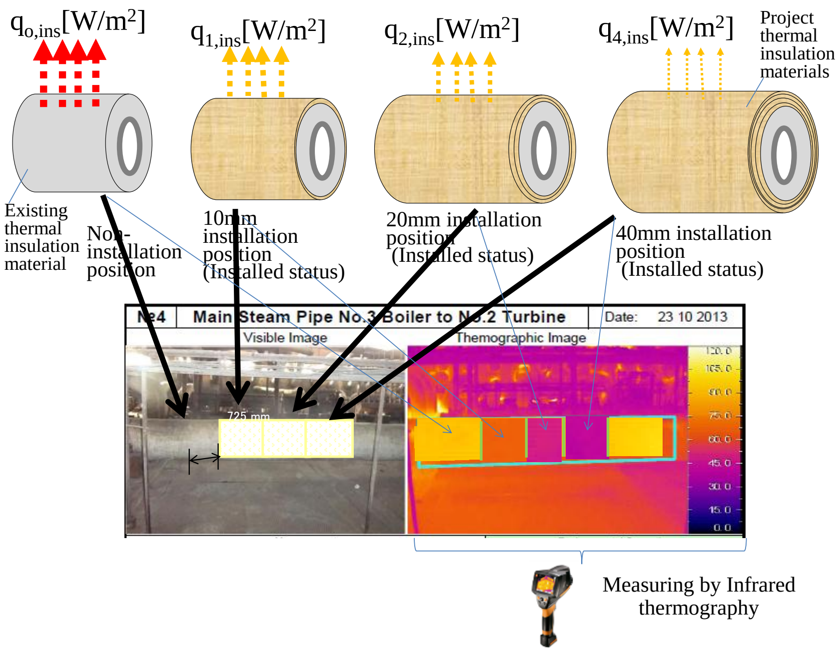


Figure AP2-6.2 Imaging figure of radiation heat quantity with sampling installation of the project thermal insulation material at each area

In that case, the decreasing rate of radiation heat quantity by project thermal insulation material at each area of 4 ones can be expressed as follows;

•In case of installation thickness of 10mm

$q_{1,ins}/\ q_{1,unins}\times(q_{0,ins}/q_{0,unins})$

•In case of installation thickness of 20mm

$q_{2,ins}/\ q_{2,unins}\times(q_{0,ins}/q_{0,unins})$

•In case of installation thickness of 40mm

$q_{4,ins}/\ q_{4,unins}\times(q_{0,ins}/q_{0,unins})$

Radiation heat quantities from 4 positions at 6 areas are shown in in Table AP2-8. Then, decreasing rate of radiation heat quantity by project thermal insulation material is shown in Table AP2-8 and Figure AP2-7.

Table AP2-8 Radiation heat quantities from 4 positions at 6 areas and the decreasing rate of radiation heat quantity by project thermal insulation material

CHP name	Sampling installation zone	Setting area	Sampling installation status	Measurement date	Pipe diameter information: Outside diameter of the existing pipe (mm)	Pipe diameter information: Thickness covered by the existing thermal insulation material (mm)	Pipe diameter information: Thickness installed by the project thermal insulation material (mm)	Pipe diameter information: Total outside diameter (m)	Pipe diameter information: Pipe direction	Ambient Temp. (°C)	Wind speed (m/s)	Surface temp.: Total area within the main steam pipe in the view of infrared thermography (°C)	Calculation values of radiation heat quantity based on JIS A9501: Total area within the main steam pipe in the view of infrared thermography (W/m²)	Decreasing rate of radiation heat quantity by project thermal insulation material (Non-dimension)
CHP3 high pressure unit	No.12 Boiler to Header (B middle)	Non-installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	93.1	643	
	No.12 Boiler to Header (B middle)	10mm installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	84.6	522	
	No.12 Boiler to Header (B middle)	20mm installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	94.5	664	
	No.12 Boiler to Header (B middle)	40mm installation area	Uninstalled	10/09/2014	273	150	0	0.573	Horizontal	38.2	0.0	95.6	680	
	No.12 Boiler to Header (B middle)	Non-installation area	Installed	10/09/2014	273	150	0	0.573	Horizontal	32.4	0.0	83.1	562	1.00
	No.12 Boiler to Header (B middle)	10mm installation area	Installed	10/09/2014	273	150	10	0.593	Horizontal	32.4	0.0	57.7	244	0.53
	No.12 Boiler to Header (B middle)	20mm installation area	Installed	10/09/2014	273	150	20	0.613	Horizontal	32.4	0.0	52.5	186	0.32
	No.12 Boiler to Header (B middle)	40mm installation area	Installed	10/09/2014	273	150	40	0.653	Horizontal	32.4	0.0	48.9	148	0.25
	No.10 Boiler to Header (B Middle)	Non-installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	98.2	754	
	No.10 Boiler to Header (B Middle)	10mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	77.0	453	
	No.10 Boiler to Header (B Middle)	20mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	80.2	496	
	No.10 Boiler to Header (B Middle)	40mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	35.0	0.0	74.6	422	
	No.10 Boiler to Header (B Middle)	Non-installation area	Installed	13/09/2014	273	150	0	0.573	Horizontal	28.5	0.0	90.4	706	1.00
	No.10 Boiler to Header (B Middle)	10mm installation area	Installed	13/09/2014	273	150	10	0.593	Horizontal	28.5	0.0	61.3	322	0.76
	No.10 Boiler to Header (B Middle)	20mm installation area	Installed	13/09/2014	273	150	20	0.613	Horizontal	28.5	0.0	54.8	248	0.53
	No.10 Boiler to Header (B Middle)	40mm installation area	Installed	13/09/2014	273	150	40	0.653	Horizontal	28.5	0.0	47.7	171	0.43
	No.13 Boiler to Header (B top)	Non-installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	69.2	257	
	No.13 Boiler to Header (B top)	10mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	77.8	364	
	No.13 Boiler to Header (B top)	20mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	77.4	359	
	No.13 Boiler to Header (B top)	40mm installation area	Uninstalled	13/09/2014	273	150	0	0.573	Horizontal	44.5	0.0	87.1	489	
	No.13 Boiler to Header (B top)	Non-installation area	Installed	13/09/2014	273	150	0	0.573	Horizontal	39.1	0.0	69.6	317	1.00
	No.13 Boiler to Header (B top)	10mm installation area	Installed	13/09/2014	273	150	10	0.593	Horizontal	39.1	0.0	69.8	319	0.71
	No.13 Boiler to Header (B top)	20mm installation area	Installed	13/09/2014	273	150	20	0.613	Horizontal	39.1	0.0	62.4	231	0.52
	No.13 Boiler to Header (B top)	40mm installation area	Installed	13/09/2014	273	150	40	0.653	Horizontal	39.1	0.0	57.2	172	0.28
CHP4	Header Pipe	Non-installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	67.9	302	
	Header Pipe	10mm installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	66.4	284	
	Header Pipe	20mm installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	67.9	302	
	Header Pipe	40mm installation area	Uninstalled	11/09/2014	377	200	0	0.777	Horizontal	37.9	0.0	67.3	295	
	Header Pipe	Non-installation area	Installed	12/09/2014	377	200	0	0.777	Horizontal	40.5	0.0	68.7	285	1.00
	Header Pipe	10mm installation area	Installed	12/09/2014	377	200	10	0.797	Horizontal	40.5	0.0	60.1	187	0.70
	Header Pipe	20mm installation area	Installed	12/09/2014	377	200	20	0.817	Horizontal	40.5	0.0	61.4	201	0.71
	Header Pipe	40mm installation area	Installed	12/09/2014	377	200	40	0.857	Horizontal	40.5	0.0	52.9	112	0.40
	No.3 Boiler to Header (B top)	Non-installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	66.6	236	
	No.3 Boiler to Header (B top)	10mm installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	75.1	338	
	No.3 Boiler to Header (B top)	20mm installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	72.9	311	
	No.3 Boiler to Header (B top)	40mm installation area	Uninstalled	15/09/2014	377	200	0	0.777	Horizontal	43.0	0.0	68.9	263	
	No.3 Boiler to Header (B top)	Non-installation area	Installed	12/09/2014	377	200	0	0.777	Horizontal	39.9	0.0	69.9	306	1.00
	No.3 Boiler to Header (B top)	10mm installation area	Installed	12/09/2014	377	200	10	0.797	Horizontal	39.9	0.0	69.7	303	0.69
	No.3 Boiler to Header (B top)	20mm installation area	Installed	12/09/2014	377	200	20	0.817	Horizontal	39.9	0.0	66.2	261	0.65
	No.3 Boiler to Header (B top)	40mm installation area	Installed	12/09/2014	377	200	40	0.857	Horizontal	39.9	0.0	58.5	175	0.51
	No.5 Boiler to Header (B top)	Non-installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	65.8	271	
	No.5 Boiler to Header (B top)	10mm installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	66.3	277	
	No.5 Boiler to Header (B top)	20mm installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	67.1	286	
	No.5 Boiler to Header (B top)	40mm installation area	Uninstalled	16/09/2014	377	200	0	0.777	Horizontal	38.5	0.0	65.5	268	
	No.5 Boiler to Header (B top)	Non-installation area	Installed	12/09/2014	377	200	0	0.777	Horizontal	35.4	0.0	62.2	260	1.00
	No.5 Boiler to Header (B top)	10mm installation area	Installed	12/09/2014	377	200	10	0.797	Horizontal	35.4	0.0	58.2	215	0.81
	No.5 Boiler to Header (B top)	20mm installation area	Installed	12/09/2014	377	200	20	0.817	Horizontal	35.4	0.0	57.4	206	0.75
	No.5 Boiler to Header (B top)	40mm installation area	Installed	12/09/2014	377	200	40	0.857	Horizontal	35.4	0.0	51.5	144	0.56

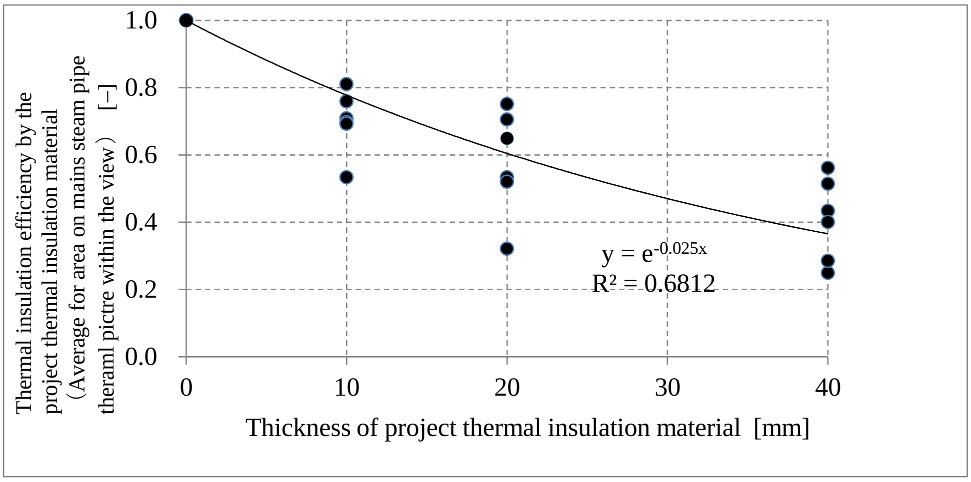


Figure AP2-7 Decreasing rate of radiation heat quantity according to installation thickness of project thermal insulation material

Decreasing rates of radiation heat quantity according to installation thickness of project thermal insulation material at 6 sampling installation areas were plotted in Figure AP2-7. Furthermore, an exponential approximation formula ($y=e^{-0.025x}$) for them was entered. As a consequence, it follows that the contributing rate is 0.6812 (the correlation coefficient is 0.8524.). One could argue that this correlation is significant to a satisfactory extent although sample correlation coefficient is 0.575067 in case of in case sample size of 19 (n=19) and significance level of 1% (α=0.01).

According to the exponential approximation formula, initial thermal insulation efficiency of the project thermal insulation material (=1–decreasing rate) equals to 0.22 (in case of installation thickness of 10mm), 0.39 (in case of installation thickness of 20mm) and 0.63 (in case of installation thickness of 40mm). These values are applied to the representative value for initial thermal insulation efficiency of the project thermal insulation material (parameter fixed ex ante) as the common ones between CHP3 and CHP4.

Table AP2-9. The representative value for initial thermal insulation efficiency of the project thermal insulation material $f_{PJI\text{-}eff}$ (parameter fixed ex ante)

Initial thermal insulation efficiency in case of installation thickness of 10mm	0.22	Non-dimension
Initial thermal insulation efficiency in case of installation thickness of 20mm	0.39	
Initial thermal insulation efficiency in case of installation thickness of 40mm	0.63	

Generally speaking, insulation effect at high surface temperature area is higher than one at low surface temperature area.
In this study, sampling installation works have been comparatively carried out at low temperature areas with the objective of safety at both of CHP3 and CHP4.
Therefore, actual performance for insulation effect is expected to be higher than result by this study.

In spite of data analysis with a certain amount of variation, the representative value for initial thermal insulation efficiency by the project thermal insulation material was calculated according to the approximation formula. However, quantification of project radiation heat quantity (after thermal insulation installation) $qR_{PJ,y}$ is performed in conservative manner due to the following reasons;

- In this study, sampling installation works have been carried out at low temperature positions of existing surface with the objective of safety at both of CHP3 and CHP4. So, performance of insulation effect for this study is thought to be lower than the actual one.
- Project radiation heat quantity is calculated by multiplying reference radiation heat quantity by initial thermal insulation efficiency of the project thermal insulation material. Reference radiation heat quantity qR_{RE} (parameter fixed ex ante) is identified as considerable conservative value.

Appendix 3

Formulae for calculation of radiation quantity of heat based on JIS A9501 (Standard practice for thermal insulation works)

<u>Calculation of radiating quantity of heat</u>

1) Measurement data

•Ambient temperature θa [°C] by actual measurement

•Average surface temperature θse [°C] by actual measurement

•Wind velocity w [m/s] by actual measurement

•Emissivity ε [-] by comparison of thermographic images and actual measurements

•Exterior diameter of thermal insulation materials De [m] by actual measurements or plant specification

2) Calculation of radiative part of surface coefficient (hr) [W/m^2・K]

$hr = \varepsilon \times \delta \times \{(\theta se+273.15)^4 - (\theta a+273.15)^4\}/(\theta se-\theta a)$

δ:Stefan Boltzmann coefficient (=5.67×10^{-8}) [W/m^2・K^4]

3) Calculation of convective part of surface coefficient (hcv) [W/m^2・K]

i) Upward plane

$hcv = 3.26 \times (\theta se - \theta a)^{0.25} \times \{(w + 0.348)/0.348\}^{0.5}$

ii) Downward plane

$hcv = 2.28 \times (\theta se - \theta a)^{0.25} \times \{(w + 0.348)/0.348\}^{0.5}$

iii) Vertical plane and pipe

•In case Abs(θse-θa)≥10°C

$hcv = 2.56 \times (\theta se - \theta a)^{0.250} \times \{(w + 0.348)/0.348\}^{0.5}$

•In case Abs(θse-θa)<10°C

$hcv = (3.61+0.094 \times (\theta se - \theta a)) \times \{(w + 0.348)/0.348\}^{0.5}$

v) Horizontal pipe

$hcv = 1.19 \times ((\theta se-\theta a)/De)^{0.250} \times \{(w + 0.348)/0.348\}^{0.5}$

4) Calculation of surface coefficient of heat transfer (hse) [W/m^2・K]

$hse = hr + hcv$

5) Calculation of radiating quantity of heat (q) [W/m^2]

$q = hse \times (\theta se - \theta a)$

Conversion of radiating quantity of heat by ambient temperature

$$q' = (\theta i - \theta a') / (\theta i - \theta a) \times q$$

q	Radiating quantity of heat before conversion	W/m^2
q'	Radiating quantity of heat after conversion	W/m^2
θa	Ambient temperature before conversion	°C
$\theta a'$	Ambient temperature for conversion	°C
θi	Temperature of internal fluid before conversion	°C

Appendix 4

Identification of decreasing rate from initial thermal insulation efficiency of the project thermal insulation material according to measurement data thermal conductivity for project thermal insulation material in conservative manner

Table AP4-1 Parameters list related to heat quantity in 3 cases (Reference status, initial status of project activity and Status for used project thermal insulation material) and magnitude relation of them

	Physical situation for heat transfer in reference case (Non-installation of project thermal insulation material)		Physical situation for heat transfer at the progressed time of project activity (Just after *y* years later since installation of project thermal insulation materials)		Physical situation for heat transfer at the starting time of project activity (Just when new project thermal insulation materials are installed)
Radiation heat quantity [W/m^2]	qR_{NI}	>	$qR_{PJI,y}$	>	$qR_{PJI,0}$ (well-known)
Thickness of existing thermal insulation material [m]	d_{ExtI} (well-known)	=	d_{ExtI} (well-known)	=	d_{ExtI} (well-known)
Thickness of project thermal insulation material [m]			d_{PJI} (well-known)	=	d_{PJI} (well-known)
Internal fluid (steam) temp. [°C]	θis (well-known and const.)	=	θis (well-known)	=	θis (well-known)
Interfacial temp between existing thermal insulation material and project one [°C]			$\theta is_{PJ,y}$	<	$\theta is_{PJ,o}$ (well-known by theoretical calculation)
Surface temp. [°C]	θse_{ExtI} (well-known)	>	$\theta se_{PJI,y}$	>	$\theta se_{PJI,0}$ (well-known)
Ambient temp. [°C]	θa_{NI} (well-known)	>	$\theta a_{PJ,y}$	>	$\theta a_{PJ,0}$ (well-known)
Thermal conductivity of existing thermal insulation material [W/m･K]	$\lambda_{ExtI,NI}$ (well-known)	<	$\lambda_{ExtI,y}$	<	$\lambda_{ExtI,0}$ (well-known by theoretical calculation)
Thermal conductivity of project thermal insulation material [W/m･K]			$\lambda_{PJI,y}$ (by actual measurement)	>	$\lambda_{PJI,0}$ (by actual measurement)
Surface coefficient of heat transfer [W/m^2･K]	α_{ExtI} (well-known)	<	$\alpha_{PJI,y}$	<	$\alpha_{PJI,0}$ (well-known)

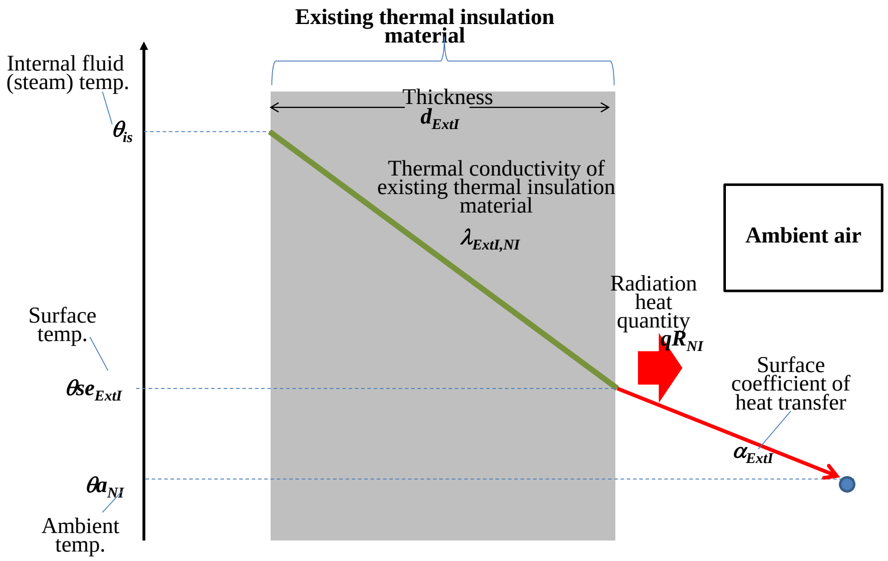


Figure AP4-1.1 Outline drawing of heat transfer in reference case

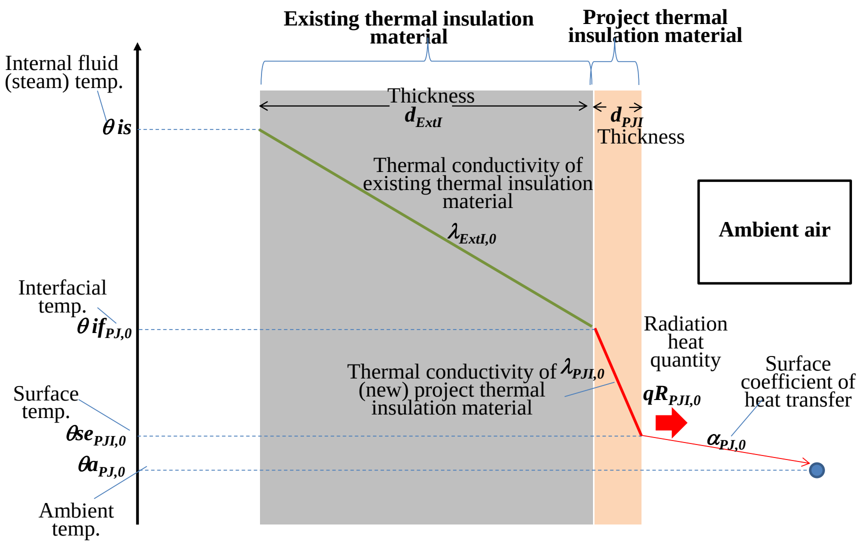


Figure AP4-1.2 Outline drawing of heat transfer at the starting time of project activity

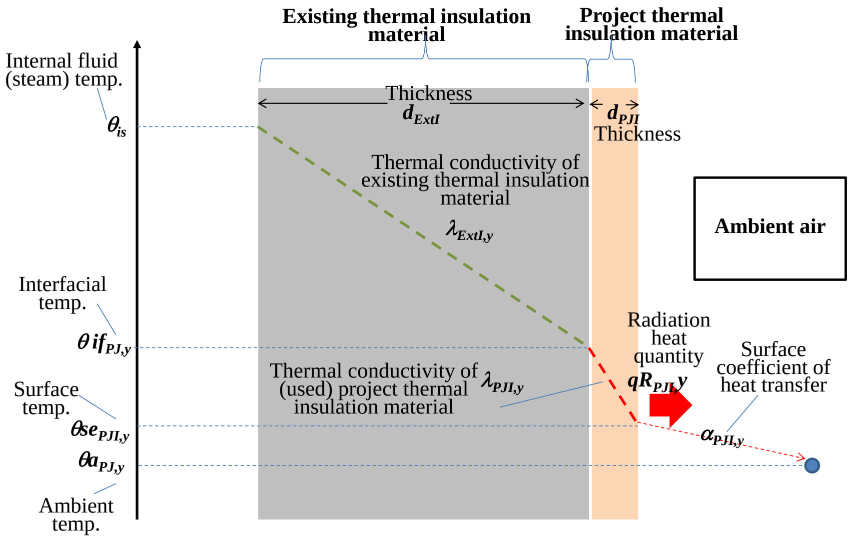


Figure AP4-1.3 Outline drawing of heat transfer at the progressed time of project activity

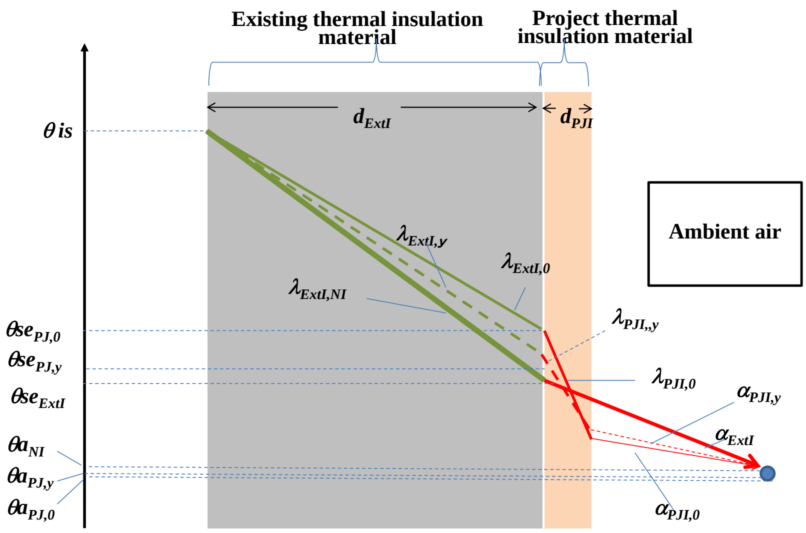


Figure AP4-1.4 Overlapping display of all statuses

For heat transfer at the starting time of project activity (Just when new project thermal insulation materials are installed), parameters in Table AP4-1 are theoretically shown as the following relational expression;

$$qR_{PJ,0} = \frac{\theta is - \theta if_{PJ,0}}{\frac{d_{ExtI}}{\lambda_{Ext,0}}} = \frac{\theta if_{PJ,0} - \theta se_{PJI,0}}{\frac{d_{PJI}}{\lambda_{PJI,0}}} = \frac{\theta se_{PJI,0} - \theta a_{PJ,0}}{\frac{1}{\alpha_{PJ,0}}} = \frac{\theta is - \theta a_{PJ,0}}{\frac{d_{ExtI}}{\lambda_{Ext,0}} + \frac{d_{PJI}}{\lambda_{PJI,0}} + \frac{1}{\alpha_{PJI,0}}} \qquad (4\text{-}1)$$

Next, for heat transfer at the progressed time of project activity (Just after y years later since installation of project thermal insulation materials), parameters in Table AP4-1 are theoretically shown as the following equation;

$$qR_{PJ,y} = \frac{\theta is - \theta a_{PJ,y}}{\frac{d_{ExtI}}{\lambda_{Ext,y}} + \frac{d_{PJI}}{\lambda_{PJI,y}} + \frac{1}{\alpha_{PJ,y}}} \quad (4\text{-}2)$$

Since $\theta a_{PJ,y} > \theta a_{PJ,0}$, $\lambda_{ExtI,y} < \lambda_{ExtI,0}$ and $\alpha_{PJI,0} < \alpha_{PJI,y}$ just as it happened,
$qR_{PJ,y}$ can be conservatively calculated as the following equation
in case that we have an assumption that $\theta a_{PJ,y} = \theta a_{PJ,0}$, $\lambda_{ExtI,y} = \lambda_{ExtI,0}$ and $\alpha_{PJI,0} = \alpha_{PJI,y}$;

$$qR_{PJ,y} = \frac{\theta is - \theta a_{PJ,0}}{\frac{d_{ExtI}}{\lambda_{Ext,0}} + \frac{d_{PJI}}{\lambda_{PJI,y}} + \frac{1}{\alpha_{PJ,0}}} \quad (4\text{-}2)'$$

Furthermore, according to “G. Calculation equations of project emissions project emissions”, $qR_{PJ,0}$ *and* $qR_{PJ,y}$ are shown as the following equations;
$qR_{PJ,0} = qR_{RE} * (1 - f_{PJI\text{-}eff})$
$qR_{PJ,y} = qR_{RE} * \{1 - f_{PJI\text{-}eff} \times (1 - f_{PJI\text{-}dec,y})\}$

qR_{RE}	Reference radiation heat quantity (before thermal insulation installation) from main steam pipe linage at the thermal power plant ←Parameter fixed ex-ante	W/m^2
$f_{PJI\text{-}eff}$	Initial thermal insulation efficiency by the project thermal insulation material ←Parameter fixed ex-ante	Non-dimension
$f_{PJI\text{-}dec,y}$	Decreasing rate from initial thermal insulation efficiency of the project thermal insulation material ←Monitoring parameter	Non-dimension

So, $f_{PJI\text{-}dec,y}$ is shown as the following equations;
$f_{PJI\text{-}dec,y} = 1 - 1/f_{PJI\text{-}eff} + qR_{PJ,y} \times (1 - f_{PJI\text{-}eff}) / qR_{PJ,0} / f_{PJI\text{-}eff}$ (4-3)

On the other hand, the following 2 parameters are actually measured.

$\lambda_{PJI,0}$	Thermal conductivity of new project thermal insulation material (before installation)	W/m･K
$\lambda_{PJI,y}$	Thermal conductivity of used project thermal insulation material after y years later since installation	W/m･K

For now, we have an assumption that $\lambda_{PJI,y}$ would be higher by 10% than $\lambda_{PJI,0}$.

Furthermore, if we apply above-mentioned 3 relational expression ((4-1), (4-2)' and (4-3)) to thermographic image data in Table AP2-8 (Radiation heat quantities from 4 areas at 6 positions and the decreasing rate of radiation heat quantity by project thermal insulation material), $f_{PJI\text{-}dec,y}$ can be calculated based on $qR_{PJ,y}$ of calculated value and $f_{PJI\text{-}eff}$ of parameter fixed ex-ante as the following table;

Table AP4-2 Identification of decreasing rate from initial thermal insulation efficiency of the project thermal insulation material ($f_{PJI\text{-}dec,y}$)

CHP 名	サンプル施工ゾーン	設定箇所	サンプル施工状態	計測日	プロジェクト保温材の初期状態からの放散熱量	内部蒸気温度	界面温度	既存保温材厚み	既存保温材の熱伝導率	界面温度	プロジェクト保温材の表面温度	プロジェクト保温材の厚み	プロジェクト保温材の熱伝導率	プロジェクト保温材の表面温度	周辺環境温度	表面熱伝導率	プロジェクト保温材の、使用前に対する、使用後の熱伝導率上昇率	使用後のプロジェクト保温材の熱伝導率	(使用後の)プロジェク保温材からの放散熱量	放散熱量の上昇率	当初の断熱効率	当初の断熱効果からの低減率
					$qR_{PJI,0}$	θIS	$\theta if_{PJ,0}$	d_{ExtI}	$\lambda_{ExtI,0}$	$\theta if_{PJ,0}$	$\theta se_{PJI,0}$	d_{PJI}	$\lambda_{PJI,0}$	$\theta se_{PJI,0}$	$\theta a_{PJ,0}$	$\alpha_{PJI,0}$	$\lambda_{PJI,y}/\lambda_{PJI,0}-1.0$	$\lambda_{PJI,y}$	$qR_{PJ,y}=qR_{PJ,0}*(1-f_{PJI\text{-}dec,y})$	$(qR_{PJ,y}-qR_{PJ,0})/qR_{PJ,0}$	$f_{PJI\text{-}eff}$	$f_{PJI\text{-}dec,y}=1-1/f_{PJI\text{-}eff}+q_{RPJ,y}*(1-f_{PJI\text{-}eff})/q_{RPJ,0}/f_{PJI\text{-}eff}$
					W/m²	°C	°C	m	W/m•K	°C	°C	m	W/m•K	°C	°C	W/m²•K	–	W/m•K	W/m²	–	–	–
CHP3	No.12 Boiler to Header (B middle)	10mm installation area	Installed	10/09/2014	243.6	530	159.2	0.150	0.09854	159.2	57.7	0.010	0.02400	57.7	32.4	9.6281	0.1000	0.02640	248.2	0.0189	0.22	0.0670
	No.12 Boiler to Header (B middle)	20mm installation area	Installed	10/09/2014	186.3	530	207.8	0.150	0.08675	207.8	52.5	0.020	0.02400	52.5	32.4	9.2706	0.1000	0.02640	191.8	0.0292	0.39	0.0457
	No.12 Boiler to Header (B middle)	40mm installation area	Installed	10/09/2014	148.2	530	295.8	0.150	0.09491	295.8	48.9	0.040	0.02400	48.9	32.4	8.9797	0.1000	0.02640	155.2	0.0472	0.63	0.0277
	No.10 Boiler to Header (B Middle)	10mm installation area	Installed	13/09/2014	322.4	530	195.6	0.150	0.14464	195.6	61.3	0.010	0.02400	61.3	28.5	9.8298	0.1000	0.02640	330.5	0.0250	0.22	0.0885
	No.10 Boiler to Header (B Middle)	20mm installation area	Installed	13/09/2014	247.9	530	261.4	0.150	0.13840	261.4	54.8	0.020	0.02400	54.8	28.5	9.4245	0.1000	0.02640	257.5	0.0389	0.39	0.0608
	No.10 Boiler to Header (B Middle)	40mm installation area	Installed	13/09/2014	171.5	530	333.5	0.150	0.13092	333.5	47.7	0.040	0.02400	47.7	28.5	8.9317	0.1000	0.02640	180.9	0.0546	0.63	0.0321
	No.13 Boiler to Header (B top)	10mm installation area	Installed	13/09/2014	318.8	530	202.6	0.150	0.14607	202.6	69.8	0.010	0.02400	69.8	39.1	10.3844	0.1000	0.02640	326.8	0.0252	0.22	0.0894
	No.13 Boiler to Header (B top)	20mm installation area	Installed	13/09/2014	230.7	530	254.6	0.150	0.12565	254.6	62.4	0.020	0.02400	62.4	39.1	9.8999	0.1000	0.02640	239.2	0.0369	0.39	0.0577
	No.13 Boiler to Header (B top)	40mm installation area	Installed	13/09/2014	172.1	530	344.0	0.150	0.13874	344.0	57.2	0.040	0.02400	57.2	39.1	9.5063	0.1000	0.02640	181.7	0.0561	0.63	0.0329
CHP4	Header Pipe	10mm installation area	Installed	12/09/2014	187.4	550	138.2	0.200	0.09104	138.2	60.1	0.010	0.02400	60.1	40.5	9.5636	0.1000	0.02640	190.1	0.0141	0.22	0.0501
	Header Pipe	20mm installation area	Installed	12/09/2014	201.3	550	229.2	0.200	0.12550	229.2	61.4	0.020	0.02400	61.4	40.5	9.6325	0.1000	0.02640	207.5	0.0309	0.39	0.0483
	Header Pipe	40mm installation area	Installed	12/09/2014	111.6	550	239.0	0.200	0.07178	239.0	52.9	0.040	0.02400	52.9	40.5	9.0026	0.1000	0.02640	115.5	0.0343	0.63	0.0202
	No.3 Boiler to Header (B top)	10mm installation area	Installed	12/09/2014	302.7	550	195.8	0.200	0.17092	195.8	69.7	0.010	0.02400	69.7	39.9	10.1571	0.1000	0.02640	309.6	0.0230	0.22	0.0815
	No.3 Boiler to Header (B top)	20mm installation area	Installed	12/09/2014	261.2	550	283.9	0.200	0.19627	283.9	66.2	0.020	0.02400	66.2	39.9	9.9310	0.1000	0.02640	271.7	0.0404	0.39	0.0631
	No.3 Boiler to Header (B top)	40mm installation area	Installed	12/09/2014	175.0	550	350.2	0.200	0.17527	350.2	58.5	0.040	0.02400	58.5	39.9	9.4112	0.1000	0.02640	184.6	0.0548	0.63	0.0322
	No.5 Boiler to Header (B top)	10mm installation area	Installed	12/09/2014	215.4	550	147.9	0.200	0.10713	147.9	58.2	0.010	0.02400	58.2	35.4	9.4461	0.1000	0.02640	218.8	0.0161	0.22	0.0571
	No.5 Boiler to Header (B top)	20mm installation area	Installed	12/09/2014	206.3	550	229.4	0.200	0.12870	229.4	57.4	0.020	0.02400	57.4	35.4	9.3791	0.1000	0.02640	212.8	0.0313	0.39	0.0490
	No.5 Boiler to Header (B top)	40mm installation area	Installed	12/09/2014	144.2	550	291.9	0.200	0.11178	291.9	51.5	0.040	0.02400	51.5	35.4	8.9593	0.1000	0.02640	150.6	0.0444	0.63	0.0260

According to all data in Table AP4-2, magnitude relation of $f_{PJI\text{-}dec,y}$ (Decreasing rate from initial thermal insulation efficiency of the project thermal insulation material) to $(\lambda_{PJI,y}-\lambda_{PJI,0})/\ \lambda_{PJI,0}$ (Increasing rate of thermal conductivity for used project thermal insulation material from initial status) is shown as follows;

$$f_{PJI\text{-}dec,y} = 1 - 1/f_{PJI\text{-}eff} + qR_{PJ,y}\times(1- f_{PJI\text{-}eff})/qR_{PJ,0}/f_{PJI\text{-}eff} < (\lambda_{PJI,y}-\lambda_{PJI,0})/\ \lambda_{PJI,0}$$

Therefore, $f_{PJI\text{-}dec,y}$ can be identified as the following equation in conservative manner, based on measurement data thermal conductivity for project thermal insulation material.

$$f_{PJI\text{-}dec,y} = (\lambda_{PJI,y}-\lambda_{PJI,0})/\ \lambda_{PJI,0}$$

Furthermore, $\lambda_{PJI,y}$ and $\lambda_{PJI,0}$ are identified by the weighted average value for temperature range between 50°C and 300°C with consideration for operating temperature range, according to interfacial temp. and surface temp. with installation of project thermal insulation material in Table AP4-2.