Converting Lower Heating Value Tested Heat Rate to Higher Heating Value Heat Rate Adjusted to Standardized ISO conditions

For this particular study, the general process to convert a performance tested heat rate at ambient conditions using Lower Heating Value (LHV) to a heat rate to standardized ISO conditions using Higher Heating Value (HHV) involves the following general steps shown below:

Table 1: Stepwise Conversions

Step	Beginning Value	End Value	Conversion Factor Description	Conversion Factor Source
1	LHV Heat Rate at Tested Ambient Conditions 5800.1 btu/kWh LHV	LHV Heat Rate at Design Conditions 5714.4 btu/kWh LHV	Correction from measured performance test results to design-condition performance test results, all using LHV	Manufacturer performance curves, corrected design-condition value listed in Final Performance Test Report
2	LHV Heat Rate at Design Conditions 5714.4 btu/kWh LHV	LHV Heat Rate at ISO Conditions 5704.6 btu/kWh LHV	Correction from design-condition performance test results to ISO-condition performance test results, all using LHV	Manufacturer performance curves, factor provided in 5/22/18 email. Calculation requires division by 1.001718
3	LHV Heat Rate at ISO Conditions 5704.6 btu/kWh LHV	HHV Heat Rate at ISO Conditions 6320.7 btu/kWh LHV	Correction from ISO-condition performance test results at LHV to ISO-condition performance test results at HHV	Manufacturer provided conversion, provided in 5/29/18 email. Calculation requires multiplication by 1.108.

Performance testing was conducted on the Grand River Energy Center Unit 3 (GREC U3) on July 6-7, 2017 to determine net electrical output and heat rate. Three separate test runs were conducted at ambient conditions. The measured heat rate, at ambient conditions, averaged across the three test runs was 5800.1 btu/kWh LHV, as indicated in **Table 2** below under “Measured Test Results”.

<u>Step 1</u>

The measured heat rate from the test runs was then converted back to specified design conditions, to correct for variations between ambient conditions during the test and the as-designed conditions such as temperature, pressure, and humidity. Design conditions included the following:

<u>GREC U3 Design Conditions</u>

- Temperature = 59 F
- Pressure = 14.367 psia
- Relative Humidity = 65%

This correction was performed using manufacturer-provided performance curves specific to the project equipment. Correction to design conditions yielded a heat rate of 5,714.4 btu/kWh LHV, as seen in Table 1 under "Corrected Test Results."

Table 2: Performance Test Result Summary

Parameter	Units	Guarantee	Measured Test Results	Corrected Test Results	Margin	Pass / Fail
Unfired Net Electrical Output	kW	449,960	444,232	450,521	561	Pass
Unfired Net Heat Rate	Btu/kWh LHV	5,723	5,800.1	5,714.4	8.6	Pass

Step 2

The heat rate, corrected to design conditions, then requires another subsequent conversion factor to adjust it to standardized ISO conditions. Adjustment to standardized ISO conditions is a statutory requirement of ORS 469.503(2)(a). Standardized ISO conditions include the following:

Standardized ISO Conditions

- Temperature = 59 F
- Pressure = 14.7 psia
- Relative Humidity = 60%

Similar to earlier corrections from as-tested conditions to design conditions, the correction from design to ISO conditions is performed using a manufacturer-provided correction factor. Per the turbine manufacturer, Mitsubishi Hitachi Power Systems Americas (MHPSA), this correction is performed by dividing the design condition Corrected Test Result (5714.4 btu/kWh LHV) by a factor of 1.001718. This conversion factor was received in an email on May 22, 2018 from Jason Richardson, Performance & Testing Engineer for MHPSA. ***See Attachment A for documentation of email correspondence***. This conversion yields the following calculation:

$$Heat\ Rate\ at\ ISO\ conditions,\ btu/kWh\ LHV = \frac{Heat\ Rate, Design\ Cond.\ Corr.\ Test\ Result, \frac{btu}{kWh} LHV}{1.001718}$$

$$Heat\ Rate\ at\ ISO\ conditions,\ btu/kWh\ LHV = \frac{5714.4 \frac{btu}{kWh} LHV}{1.001718}$$

$$Heat\ Rate\ at\ ISO\ conditions,\ btu/kWh\ LHV = 5704.6 \frac{\mathrm{btu}}{\mathrm{kWh}} LHV$$

Step 3

The final remaining conversion is to adjust the heat rate at ISO conditions using LHV to the heat rate at ISO conditions using HHV of the fuel. This is performed using a multiplier provided by the manufacturer. This conversion is performed by multiplying the Heat Rate at ISO Conditions btu/kWh LHV by 1.108[1]. This factor was received in an email dated May 29, 2018 from Jason

Richardson, Performance & Testing Engineer for MHPSA. This conversion yields the following calculation:

$$\textit{Heat Rate at ISO conditions, btu/kWh HHV} = \textit{Heat Rate at ISO conditions, btu/kWh LHV} \times 1.108$$

$$\textit{Heat Rate at ISO conditions, btu/kWh HHV} = 5704.6 \times 1.108$$

$$\textit{Heat Rate at ISO conditions, btu/kWh HHV} = 6320.7 \textit{ btu/kWh HHV}$$

Note 1: Previous documentation from ODOE on this rulemaking used a slightly different conversion from heat rate at LHV to heat rate at LHV. This previous factor was 1.109 (instead of 1.108 above). Use of this conversion factor results in a heat rate at ISO conditions of 6326.4 btu/kWh HHV.

Summary of Results

Table 3:
Values in Notice Issued on 5/30/18 vs. Values to be Recommended to EFSC on 6/29/18

	LHV to HHV Conv. Factor	HHV Heat Rate at ISO Conditions	Net CO2 Emissions Rate Threshold for Base Load Gas Plants and Non-Base Load Power Plants	Net CO2 Emissions Rate Threshold for Nongenerating Energy Facilities
Affected OARs	n/a	OAR 345-024-0570	OAR 345-024-0550 and OAR 345-024-0590	OAR 345-024-0620
Proposed in Notice of Rulemaking Issued May 29, 2018	1.109	6326.4	0.614	0.458
Recommendation to EFSC at June 29, 2018 EFSC Meeting	*1.108*	*6320.7*	*0.614*	*0.458*

Attachment A

Email Correspondence Between:

Oregon Department of Energy
and
Mitsubishi Hitachi Power Systems Americas

SIERMAN Jason * ODOE

From: SHELIDE Blake * ODOE
Sent: Tuesday, May 29, 2018 4:29 PM
To: SIERMAN Jason * ODOE
Subject: FW: MHPS performance

FYI

From: Richardson, Jason [mailto:Jason.Richardson@amer.mhps.com]
Sent: Tuesday, May 29, 2018 2:03 PM
To: SHELIDE Blake * ODOE <Blake.Shelide@oregon.gov>
Cc: Rippy, Mike <Mike.Rippy@amer.mhps.com>; Dyer, James <James.Dyer@amer.mhps.com>; Burrow, Jammie <jburrow@grda.com>; Richardson, Jason <Jason.Richardson@amer.mhps.com>
Subject: RE: MHPS performance

Blake,

Based on our standard fuel specification, we would use a multiplier of 1.108 to convert LHV to HHV.

Jason Richardson
Performance & Testing Engineer
Mitsubishi Hitachi Power Systems Americas, Inc.
400 Colonial Center Parkway, Suite 400, Lake Mary, FL 32746
Tel: (407) 688-6242
Cell: (407) 780-0813

From: SHELIDE Blake * ODOE [mailto:Blake.Shelide@oregon.gov]
Sent: Tuesday, May 22, 2018 4:44 PM
To: Richardson, Jason
Cc: Rippy, Mike; Dyer, James; Burrow, Jammie
Subject: RE: MHPS performance

Jason,

Great, thanks.

One additional question: our program looks at heat rates using btu/kWh **H**HV. The conversion I've used for LHV to HHV is 1.109. In this example, 5704.6 btu/kWh LHV x 1.109 = 6326.4 btu/kWh HHV. Does this conversion match with MHPS convention as well?

Thanks,
Blake

From: Richardson, Jason [mailto:Jason.Richardson@amer.mhps.com]
Sent: Tuesday, May 22, 2018 11:07 AM
To: SHELIDE Blake * ODOE <Blake.Shelide@oregon.gov>
Cc: Rippy, Mike <Mike.Rippy@amer.mhps.com>; Dyer, James <James.Dyer@amer.mhps.com>; Burrow, Jammie

<jburrow@grda.com>; Richardson, Jason <Jason.Richardson@amer.mhps.com>
Subject: RE: MHPS performance

Blake,

I confirm that your understanding is correct. This will account for the difference in the relative humidity and barometric pressure from the design condition to ISO conditions.

Jason Richardson
Performance & Testing Engineer
Mitsubishi Hitachi Power Systems Americas, Inc.
400 Colonial Center Parkway, Suite 400, Lake Mary, FL 32746
Tel: (407) 688-6242
Cell: (407) 780-0813

From: SHELIDE Blake * ODOE [mailto:Blake.Shelide@oregon.gov]
Sent: Tuesday, May 22, 2018 1:59 PM
To: Richardson, Jason
Cc: Rippy, Mike; Dyer, James; Burrow, Jammie
Subject: RE: MHPS performance

Jason,

Great, thanks for the factor, that is very helpful. For clarification, the factor is applied to the already corrected heat rate at design conditions, correct? Referencing the values from the GREC test report for the Heat Rate, LHV:

5714.4 / 1.001718 = 5704.60

Parameter	Units	Guarantee	Measured Test Results	Corrected Test Results	Margin	Pass / Fail
Unfired Net Electrical Output	kW	449,960	444,232	450,521	561	Pass
Unfired Net Heat Rate	Btu/kWh LHV	5,723	5,800.1	5,714.4	8.6	Pass

Please confirm if my understanding is correct.

Thanks,
Blake

Blake Shelide, PE
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From: Richardson, Jason [mailto:Jason.Richardson@amer.mhps.com]
Sent: Tuesday, May 22, 2018 10:40 AM
To: Burrow, Jammie <jburrow@grda.com>
Cc: Rippy, Mike <Mike.Rippy@amer.mhps.com>; SHELIDE Blake * ODOE <Blake.Shelide@oregon.gov>; Dyer, James <James.Dyer@amer.mhps.com>; Richardson, Jason <Jason.Richardson@amer.mhps.com>
Subject: RE: MHPS performance

Jammie,

We have a correction factor to correct the heat rate test result back to ISO conditions. Simply divide the heat rate result by 1.001718. This accounts for the relative humidity and barometric pressure differences from ISO. Hope this helps!

Jason Richardson
Performance & Testing Engineer
Mitsubishi Hitachi Power Systems Americas, Inc.
400 Colonial Center Parkway, Suite 400, Lake Mary, FL 32746
Tel: (407) 688-6242
Cell: (407) 780-0813

From: Burrow, Jammie [mailto:jburrow@grda.com]
Sent: Tuesday, May 8, 2018 8:21 AM
To: Dyer, James
Cc: Rippy, Mike; Richardson, Jason; 'Blake.Shelide@oregon.gov'
Subject: MHPS performance

James,

Mike Rippy and GRDA have been coordinating with Oregon Department of Energy to develop new standards for power plants built in Oregon. We have provided them with performance information on our plant but that information is based on contract conditions not ISO conditions. Does MHPS have heat rate information for our unit based on ISO conditions?

Thanks,

Jammie Burrow, P.E.
GREC Chief Engineer
Office 918-824-7537
Cell 918-606-1559

From: SHELIDE Blake * ODOE [mailto:Blake.Shelide@oregon.gov]
Sent: Monday, May 7, 2018 5:38 PM
To: Burrow, Jammie <jburrow@grda.com>
Subject: RE: Robert Ladd has shared files with you

This is an EXTERNAL EMAIL. Stop and think before clicking a link or opening attachments.

Also, I meant to include this table, extracted from the report, just to highlight some of the parameters I'm referring to.

GREC U3 CTG Exhaust Flow by CTG Energy Balance Calculation for HRSG & EPC						
Description	**Unit**	**Tag Number**	**Design**	**Test Run 1**	**Test Run 2**	**Test Run 3**
Power Measurements						
Generator Gross Power Output	kW		314,700.0	307,546.5	311,860.0	313,016.5
Power Factor	-		0.90	1.00	1.00	1.00
Frequency	Hz		60.0	60.0	60.0	60.0
Measured Excitation Current	A		65.0	2,020.5	2,045.3	2,040.1
Auxiliary Power	V		500.0	114.2	115.0	113.0
Pressure Measurements						
Barometric Pressure	psia		14.367	14.426	14.424	14.424
Static Inlet Chiller Coil Loss	inH2O		1.000	0.646	0.645	0.649
Static Inlet Loss	inH2O		5.000	5.000	5.000	5.000
Static Exhaust Pressure Loss	InH2O		16.000	15.356	15.550	15.624
Fuel Supply Pressure	psia		650.000	706.016	705.446	705.451
TCA Inlet Pressure	psia		3000.0	2664.2	2672.0	2666.7
TCA Outlet Pressure	psia		3000.0	2604.8	2613.8	2607.9
CT Cooling Steam Inlet Pressure	psia		517.6	528.0	530.8	531.7
CT Cooling Steam Outlet Pressure	psia		419.9	430.7	432.4	433.0
Temperature Measurements						
Ambient DB Temp	Deg F		59.0	79.3	75.4	74.1
Ambient RH	%		65.00%	76.19%	81.11%	84.12%
Compressor Inlet Temp	Deg F		59.0	79.3	75.3	74.2
Compressor Inlet RH	%		65.00%	76.19%	81.11%	84.12%
Fuel temp at turbine	Deg F		449.0	454.9	455.5	455.0
Exhaust Temp	Deg F		1,188.0	1,191.5	1,188.9	1,188.2

From: SHELIDE Blake * ODOE
Sent: Monday, May 7, 2018 3:34 PM
To: 'Burrow, Jammie' <jburrow@grda.com>
Subject: RE: Robert Ladd has shared files with you

Jammie,

Thanks. One initial question I have is related to the Design parameters (to which all field-tested conditions are corrected/adjusted for performance verification) that are slightly different than ISO standard conditions (which is appropriate and I imagine more representative of expected site conditions). Would it be possible for GRDA (or more likely contractors or turbine manufacturer) to re-adjust to determine heat rate at ISO conditions? Do you know if that may have been done already? I believe all the correction curves are in the report and I would be able to back out the factors to do the correction myself, but it would probably take some time. I thought that the party who did the testing may be able to more easily perform a heat rate correction back to ISO conditions, instead of plant design conditions. It looks like these are actually pretty close (same temperature, 14.367 vs. 14.7 psig, etc. 65% vs. 60% RH, etc.).

This may be more of a question for MHPS, but I wanted to get your input first. Thanks again for your help.

-Blake

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From: Burrow, Jammie [mailto:jburrow@grda.com]
Sent: Tuesday, May 1, 2018 12:09 PM
To: SHELIDE Blake * ODOE <Blake.Shelide@oregon.gov>
Subject: RE: Robert Ladd has shared files with you

Yes, I would be your best choice.

Jammie Burrow, P.E.
GREC Chief Engineer
Office 918-824-7537
Cell 918-606-1559

From: SHELIDE Blake * ODOE [mailto:Blake.Shelide@oregon.gov]
Sent: Tuesday, May 1, 2018 2:07 PM
To: Burrow, Jammie <jburrow@grda.com>
Subject: RE: Robert Ladd has shared files with you

Jammie,

I may have some questions on this as I review (particularly around adjustment to design/standard conditions). Are you the right person to contact if I do?

Thanks,
Blake

Mitsubishi Hitachi Power Systems Americas, Inc.
www.MHPowerSystems.com

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