GPCALCS™

The Performance Engineer's Toolbox

GPCALCS™ Version 7

August 2025

EtaPRO®

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Printed in the United States of America

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Introduction

Introduction

Welcome to GPCALCS™ Version 7! You have acquired what we believe to be the best value in thermal performance software available today to increase your personal productivity as well as your plant's efficiency.

Equipment Performance Workbooks

This "toolbox" of Microsoft® Excel workbooks is the culmination of thousands of man-hours of development and testing for accuracy and usefulness by experienced power and process plant performance engineers under actual test conditions. Each workbook is organized for convenient data entry and report generation. Using these workbooks, the experienced performance engineer can quickly and accurately calculate equipment efficiencies consistent with industry methodology. Workbooks are included for:

- Boiler/Air Heater (Coal) Performance
- Boiler/Air Heater (Oil/Gas) Performance
- Compressor Performance
- Condenser Performance
- Controlled Extraction Turbine Performance
- Cooling Tower Performance
- Fan Performance
- Feedwater Heater Performance
- Flow Metering
- Gas Turbine Performance
- Heat Recovery Steam Generator (HRSG) Performance

- Pump Performance
- Utility Steam Turbine Performance

Performance Test Protocols

A set of Performance Test Protocols (PTPs) is included for your convenience. These generic protocols are provided in Microsoft Word format and can become the basis of a comprehensive test program…test set-up through final report! You are encouraged to modify the protocols to fit your plant's equipment in keeping with the ASME Performance Test Codes (PTCs) and good engineering practice. The following test protocols are provided:

- Air Heater
- Boiler
- Boiler Feed Pump
- Boiler Feed Pump/Turbine Set
- Compressor
- Cooling Tower
- Feedwater Heater
- Gas Turbine Generator
- Heat Recovery Steam Generator (HRSG)
- Motor Driven Pump
- Steam Surface Condenser
- Utility Steam Turbine Generator

GPCALCS Library Functions

GPCALCS Library functions allow you to calculate the thermodynamic properties of air and steam, supplied as part of the GPCALCS Excel Add-in. In addition, a tool is provided for psychrometric functions.

GPSteam™

Customer favorites — the GPSteam Properties Calculator and the GPSteam Excel Add-in — continue to be part of GPCALCS v7. Both tools allow you to choose either the ASME IFC-67 or IAPWS-IF97 Steam Table formulations.

Unit Conversion Utility

Each workbook allows for automatic engineering unit conversion (both metric and English) for user inputs, as well as any calculated values using the Unit Conversion Utility, supplied with the GPCALCS Excel Add-in, eliminates the need to manually search through unit conversion tables.

Handy Reference Library

In addition, a Handy Reference Library workbook is included that contains the following commonly used information:

- Periodic Table of the Elements
- Principle Properties of Commercial Pipe
- Typical Coal Analyses
- HHV to LHV Conversion
- Typical Fuel Oil Analyses
- Typical Natural Gas Analyses
- Psychrometric Calculator
- Gas Properties Data (over 200 gases)
- Engineering Unit Conversion Utility
- GPSteam Library Functions

Training Seminars

EtaPRO LLC hopes that the time you save in developing test procedures and conducting the performance calculations can be used effectively to analyze your performance test results for the root cause(s) of any indicated performance deficiencies. We encourage your performance engineers or any of your power or process plant personnel interested in improving efficiency to increase their knowledge and diagnostic skills by attending one of our Performance Knowledge™ Series seminars. Heat rate improvement courses, including ***Advanced Performance Analysis and Troubleshooting for Conventional Rankine Cycle Power Plants*** *and* ***Advanced Performance Analysis and Troubleshooting for Combined Cycle Power Plants*** – case study-based seminars, are offered for operations, maintenance, entry-level engineers, and experienced power plant engineers as open enrollment or onsite presentations. For information about our seminars, contact EtaPRO LLC by email at **EtaPRO-Training@etapro.com.**

Technical Support	*For GPCALCS technical support, contact EtaPRO LLC by email at* ***EtaPRO-Support@etapro.com****.*

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Getting Started

Getting Started

System Requirements

GPCALCS requires certain hardware and software components to be able to run properly:

- 1 GHz or faster 32-bit (x86) or 64-bit (x64) processor)
- **Microsoft Windows Server Operating System**. You must use a version of the Microsoft Windows operating system that is actively supported by Microsoft and is compatible with the .NET 4.8 Framework (**http://msdn.microsoft.com/en-us/library/8z6watww.as**™).
- **Microsoft Office** Use of a version Office that is actively supported by Microsoft is strongly recommended
- 1 gigabyte (GB) RAM (32-bit) or 2 GB RAM (64-bit)
- A hard drive with at least 100MB of available space

Installing GPCALCS v7

At the time of purchase, you will be sent a link to the download site for GPCALCS, along with a Product Key used to activate the software after installation.

Note

If GPCALCS v7 installation detects that GPCALCS v6.0 or earlier is installed on your computer, you will be prompted to uninstall it. Refer to ***Removing GPCALCS or GPSteam from Your Computer*** *in this chapter.*

If GPSteam v7 is installed on your computer, you must uninstall it prior to installing GPCALCS v7. ***You will NOT be prompted to do so.***

1. Exit any other applications that are running.
2. Browse to the folder with the GPCALCS installation files and run the **GPCALCS_Setup.exe** program.
3. Read the *License Agreement*. Check the **I agree to accept the license terms and conditions** box.
4. The default directory for the program is **C:\Program Files\EtaPRO LLC\GPCALCS 7.x**. To select a new destination folder for the program, click **Options** to display the *Setup Option*s dialog. Use the **Browse** button to locate the folder and then click **OK**.
5. Click **Install to** display the *User Account Control* dialog and click **Yes** to continue.
6. The files will be installed and when complete, the *Setup Complete* dialog displays. Click **Close**.
7. To complete the installation, you need to license the software using the **License Manager** app and enable the **GPSteam Excel Add-in** using the app in the **GPCALCS** folder.

GPCALCS Folder

The items located in the **Start|GPCALCS** folder are described below:

- **Protocols**—A set of **Equipment Performance Test Protocols** for testing power and process plant equipment. Refer to **Chapter 3** for information about using these Word templates.
- **Workbooks**—A set of **Equipment Performance Workbooks** used to calculate equipment efficiencies. Refer to **Chapter 4** for information about using these Excel workbooks.
- **GPSteam**—This item launches the *GPSteam Properties Calculator* (refer to **Chapter 18**).
- **Handy Reference**—This item launches the Excel *Handy Reference Library* workbook (refer to **Chapter 20**).
- **License Manager—**This item launches the GPCALCS Licensing tool used to activate the software.

Licensing GPCALCS

In previous versions of GPCALCS, licensing was done through a Lock Code and Key Value methodology. For GPCALCS v7, this licensing methodology was changed to require the use of a **Product Key**. A Product Key is a set of

30 alpha-numeric characters like product keys used with other software products. Licensing enables the **GPSteam Properties Calculator** and the **GPSteam Excel Add-in** and registers the software to your computer.

Note

Product Key. *Each Product Key will allow three activations so that GPGPCALCS can be installed on up to three computers.*

30-Day Trial Period. *EtaPRO LLC allows a 30-day trial period for GPGPCALCS. After the 30-day trial period expires, the GPSteam Properties Calculator and the GPSteam Excel Add-in will be disabled.*

Follow these instructions to enter the Product Key:

1. You should be given the Product Key when purchasing GPCALCS. If you have been using the 30-day trial version and now want the licensed version, contact EtaPRO LLC by email at **EtaPRO-Support@etapro.com** for assistance
2. Click the **License Manager** app in the **Start|GPCALCS 7** menu to display the *GPCALCS Licensing* dialog (refer to **Figure 2-1**).
3. Enter the Product Key and then click **Activate**. If the activation is successful, a message will display on the *License Manager* dialog indicating that the license validation was successful and further action is not required. Click **Close** to complete the licensing process.
4. If you do not have internet access, you will see this error message (refer to **Figure 2-2**).
5. Click **OK** and then click **Manual Activation to** display on the *Manual Product Activation* dialog (refer to **Figure 2-3**).
6. Click **Copy** to copy the Manual Registration Identifier to the clipboard or click **To File...** to save it to a file.
7. Open this website on a computer with internet access: **http://support.etapro.com/ManualLicense** to display **Manual Activation** website. Select the **GPCALCS V7** link and enter your **Product Key** and the **Manual Registration Identifier** in the fields provided along with your email address.
8. An Email containing your **Product Manual Activation Identifier** will be sent to your email address. If you do not receive the email or encounter difficulties during activation, please contact EtaPRO LLC by email at **EtaPRO-Support@etapro.com**. Include your **Product Key** and the file with the **Manual Registration Identifier**.

Figure 2-1 GPCALCS Licensing

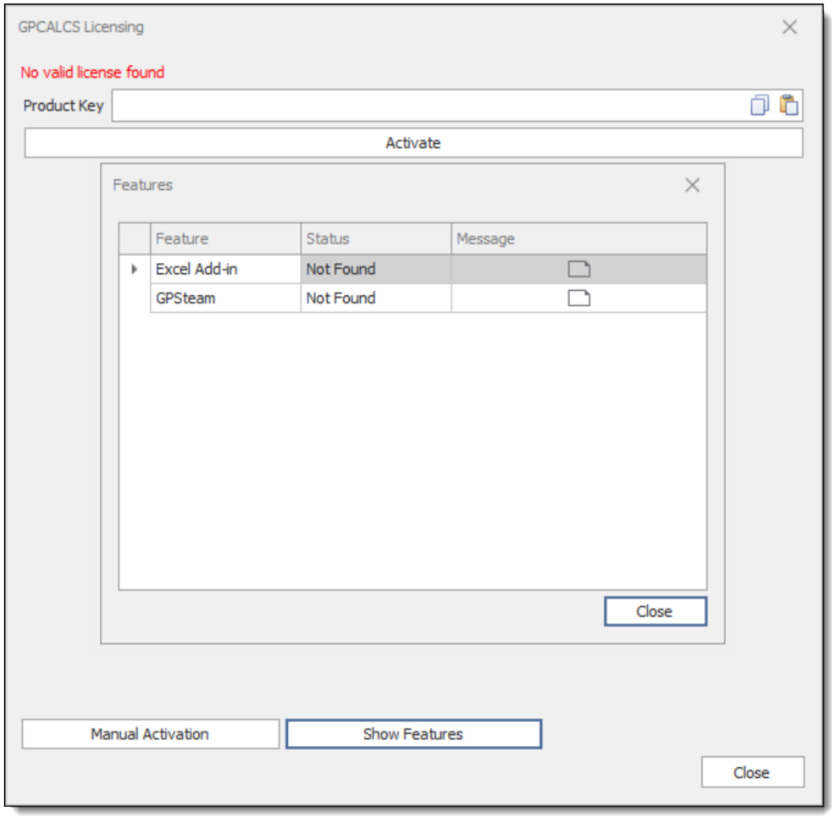


Figure 2-2
GPCALCS
Activation Error

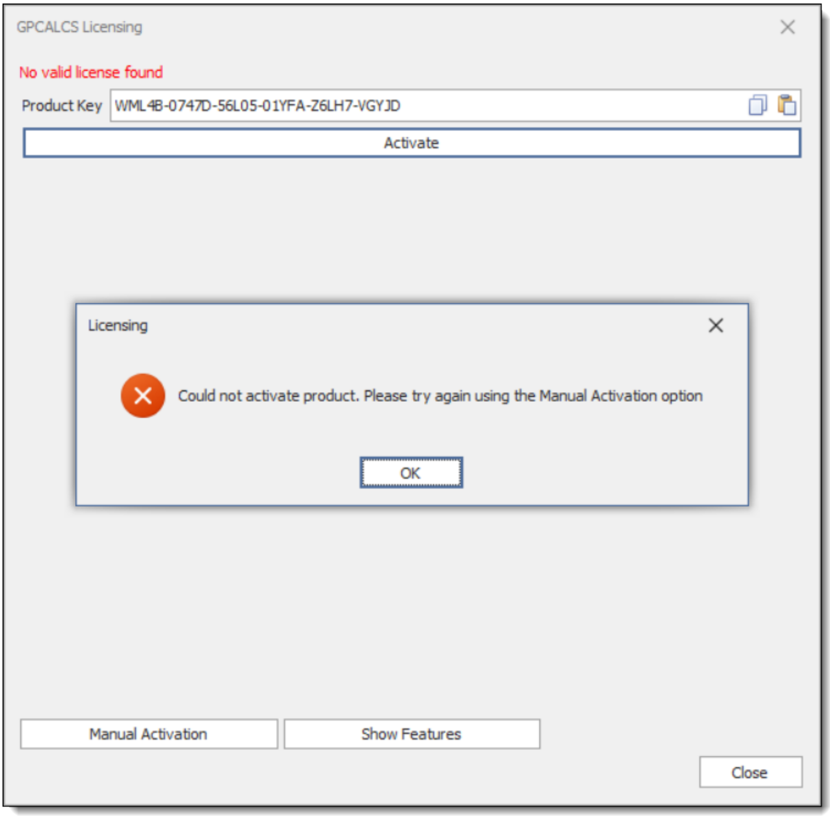
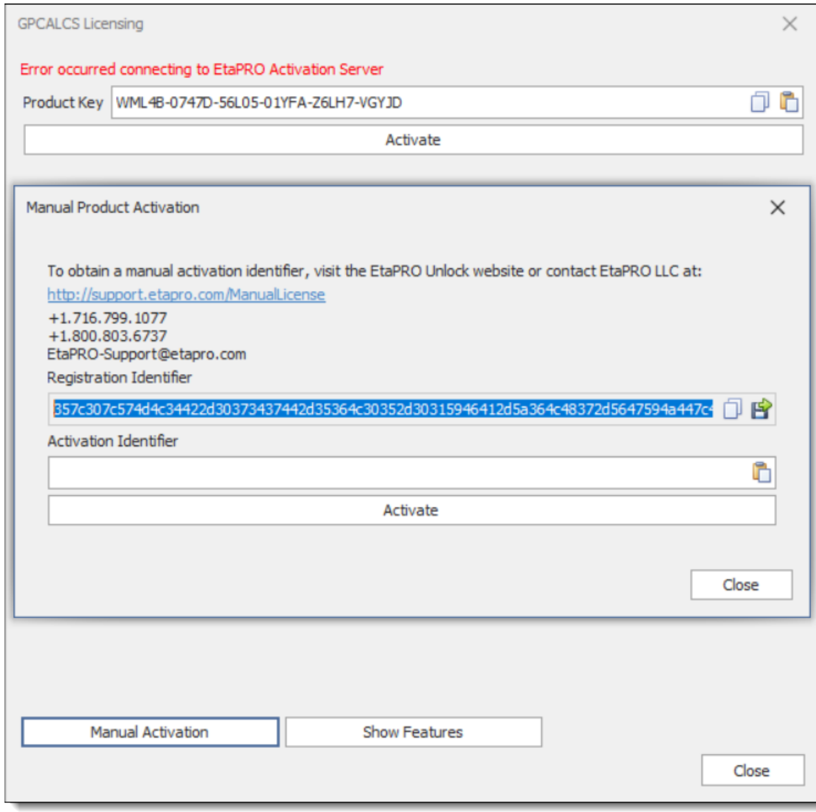


Figure 2-3
GPCALCS Manual Activation



10. Open the **License Manager** and enter the **Manual Activation Identifier** provided in the email.
11. Click **Activate** and a message will display on the *License Manager* dialog indicating that the features are now enabled. Click **Close** to complete the licensing process.
12. If you exceed your three activations and enter the Product Key, you will get a message on the *License Manager* dialog. Contact EtaPRO LLC by email at **EtaPRO-Support@etapro.com** for assistance.

Installing GPCALCS on a Different Computer

Each Product Key will allow three activations so that GPGPCALCS can be installed on up to three computers.

Removing GPCALCS or GPSteam from Your Computer

To remove GPCALCS or GPSteam from your computer:

1. Close Excel and use the disable the **GPSteam Excel Add-in** using the app in the **GPCALCS** folder.
2. Open the **Settings|Apps|Installed Apps** from the **Start** menu.
3. Click the **...** button for GPCALCS 7 to display the app menu and click **Uninstall**.

3

Performance Test Protocols

Performance Test Protocols

Using GPCALCS and Microsoft Word

Note *You should have Microsoft Word 2010 or later installed on your computer to use the Performance Test Protocols.*

GPCALCS contains a set of Performance Test Protocols (PTPs) for testing power and process plant equipment. Follow these steps to access the GPCALCS PTP templates. Refer to your Word manual or the Word **Help** menu for information about modifying, saving, and/or printing a document using these Word templates **(*.dotx**).

1. Open the GPCALCS folder to display the set of PTPs
2. Select the desired Performance Test Protocol.
3. This automatically creates a new Word document named **Document "#".doc**.
4. If the **SECURITY WARNING Macros have been disabled** message displays below, select **Enable Content**.

4

Equipment Performance Workbooks

Using GPCALCS and Microsoft Excel

Note *You must have Microsoft Excel 2010 or later installed on your computer to use the GPCALCS v7 Equipment Performance Workbooks.*

GPCALCS contains a set of Equipment Performance Workbooks that calculate the efficiencies of power and process plant equipment. Follow the steps given below to access the Equipment Performance Workbooks. Refer to your Excel manual or the Excel **Help** menu for information about modifying, saving, and/or printing a worksheet using these Excel templates **(*.xltm**).

1. Open the GPCALCS program group to display the set of Equipment Performance Workbooks.
2. Select the desired Equipment Performance Workbook.
3. This automatically creates a new workbook, named **GP "equipment name"1.xls**.
4. If the **SECURITY WARNING Macros have been disabled** message displays below, select **Enable Content**.

Workbook Protection

To prevent corruption of the workbook, cell protection is active for all worksheets by default. A password is not used. Only data entry cells shaded in orange, reference information cells or option buttons that can be changed.

Important *Data must be entered in all orange shaded cells.*

Workbook Features

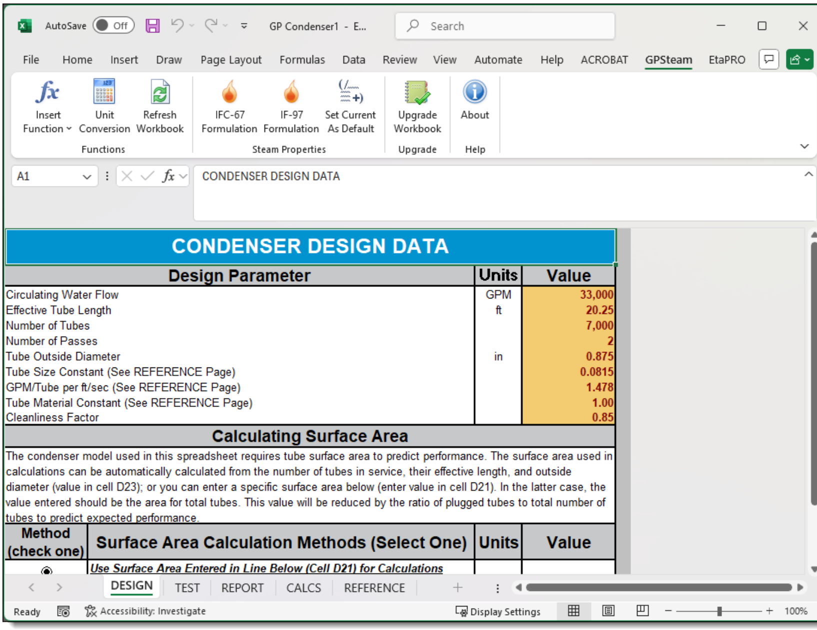
Worksheets

- **Design Data Worksheet**—Contains the design data from equipment manufacturer's specifications, as well as any process data, gas properties, ambient conditions, data required for reporting purposes, or input/calculation options for that piece of equipment.
- **Test Data Worksheet**—Contains the raw test data observed during the equipment performance test, as well as any fuel analysis, ambient conditions, data required for reporting purposes, or input/calculation options for that piece of equipment.
- **Report Worksheet**—Contains a summary report showing all the calculated results. This allows the Test Engineer to make a quick comparison between design and test values. Other reports are available, using the **Print Reports** button.
- **Calculation Worksheet(s)**—Shows the calculations performed for determination of equipment performance.
- **Plots Worksheet(s)**—Provides plots of critical data, correction curves, an energy balance, or a steam map where appropriate.
- **References Worksheet**—Provides necessary reference information for data entry where appropriate.

GPCALCS Menu

The **GPSteam** menu (refer to **Figure 4-1**) is added to the Excel menu bar when the *GPCALCS Excel Add-ins* is enabled. The menu contains the following commands:

Figure 4-1
GPSteam Menu



- **Insert Function**—Displays the Displays the list of **Air**, **Psychrometric**, and **Steam** Functions
- **Unit Conversion**—Launches the *Unit Conversion Utility* (refer to **Chapter 19**).
- **Refresh Workbook**—Recalculates the workbook.
- **Steam Properties**—Allows you to select either the IFC-67 or the IF-97 steam table formulations for the calculations and sets the current formulation as the default.
- **Upgrade Workbook**—Upgrades an Excel workbook created using Version 6.0 functions to Version 7.
- **About**—Displays the *About* dialog showing information about the GPCALCS software version loaded on the computer and Technical Support contact information.

Using Equipment Performance Workbooks

Entering Design and Test Data

Enter all the required data into the cells shaded in orange on the *Design* worksheet. Repeat this process for the *Test* worksheet. Use the worksheet buttons to move to the various data entry sections of the worksheet, when applicable.

Note	*All internal GPCALCS calculations are performed using English. units. However, you are given the option of selecting input and output units for your design and test data. For simplicity, all calculations in this manual are shown using English units.*

Calculating Results

The calculation option in Excel is set to automatic. Every time a value, formula, or name is changed, all dependent formulas in the workbook are automatically recalculated. If you experience problems, you can change to the manual mode. Select **Formulas|Calculation Option** on the Excel menu bar and select the **Manual** option. No formulas are calculated until either you press the [**F9**] key or you select **Formulas|Calculate Now** option. Before you save the workbook, return the calculation option to **Automatic**.

Printing Reports

Use the **Print Report** button on the *Reports* worksheet to display the *Print Reports* dialog (refer to **Figure 4-2**) with a list of the reports available for that Equipment Performance Workbook. An option is provided to preview the report before printing. These can include plots of critical data.

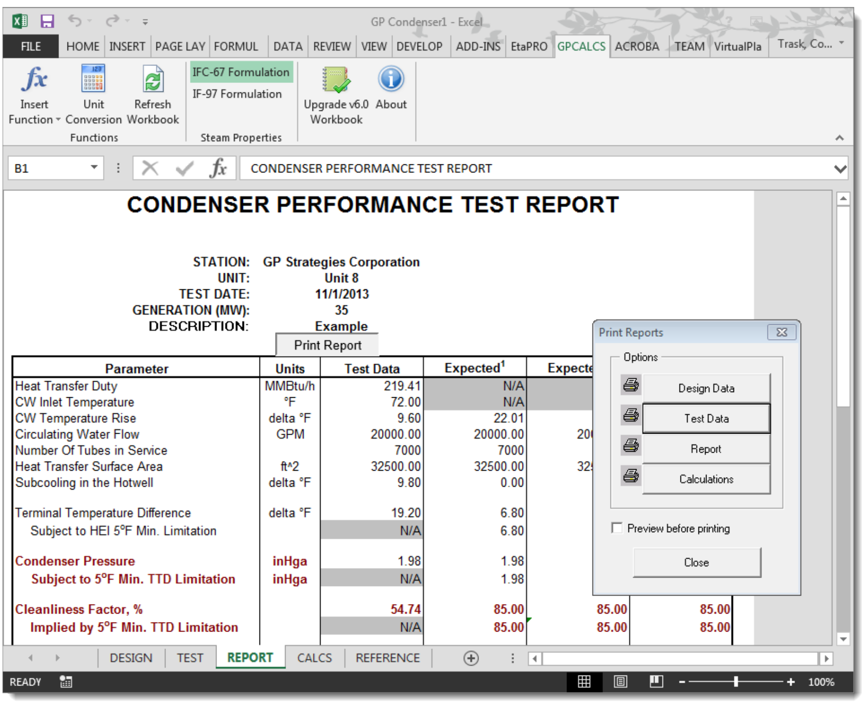


Figure 4-2
Typical Print Report Dialog Box

Saving Test Results

Click **File|Save As** on the Excel menu bar to save the file to a disk or your hard drive. It is recommended that the file be named using a standard nomenclature such as **PlantNo_EquipmentType_TestDate.xls**.

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Boiler/Air Heater Performance Workbook

Boiler/Air Heater Performance Workbooks

Two GPCALCS Boiler/Air Heater Workbooks are provided: *GP Boiler–Coal* and *GP Boiler–Oil/Gas*, dependent on the type of fuel used to fire the boilers. The coal workbook is applicable to boilers firing solid fuels singly or with oil or gas. The oil/gas workbook is applicable to boilers firing oil or natural gas singly or in combination. Because the boiler and air heaters are often tested together, the GPCALCS Boiler/Air Heater Workbooks combine performance calculations for both. Computations are performed in accordance with the ASME Performance Test Codes PTC 4, Fired Steam Generators and PTC 4.3, Air Heaters.

These workbooks calculate boiler efficiency using the ASME Loss Method. Calculated values are corrected for standard or reference conditions and compared to design values. In addition, air heater gas-side efficiency and X-ratio performance values are calculated with corrections to exit gas temperature. Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Measuring Boiler Performance

Boiler efficiency is defined as the ratio of heat absorbed by the steam and water circuits to the heat added to the boiler envelope. The principal source of heat input to the boiler is the energy released during the combustion of fuel. Other heat sources include the heat in ambient air used for combustion and the sensible heat in fuel. These last two heat sources are considered heat credits.

The heat absorbed by the boiler's steam and water circuits can be computed by measuring the individual steam and water flows, temperatures, and pressures to determine the enthalpy rise in the economizer, waterwalls, superheaters, and reheater. The accuracy of this approach, ASME Input/Output Method, is directly affected by the feedwater flow measurement. Since the uncertainty of a permanently installed plant-flow nozzle is often approximately ±3%, the ASME Loss Method is preferred for establishing boiler efficiency. The Loss Method determines the major heat losses in a steam generator as a percentage of total heat input. Given an ultimate analysis of a fossil fuel and excess air or oxygen, the workbook performs a complete combustion analysis, computes air heater leakage, determines major heat losses and credits, and predicts all air and gas flows.

Measuring Air Heater Performance

Air heaters transfer heat from the exiting flue gas, which is typically >600°F, to the incoming combustion air to increase boiler efficiency. Changes in performance greatly influence boiler efficiency as reflected in changes to the flue gas exit temperature. Flue gas exit temperature generally tends to increase as air-heater gas-side efficiency decreases. It may also decrease if there is excessive leakage of combustion air into the flue gas path. This temperature can also be affected by factors not related to air heater performance, such as the amount of excess air.

What You'll Need

Analyzing boiler performance requires a significant amount of field data. The "Contract Data Sheet" or "Boiler Performance Summary" is the best source for design data.

Design Data

The following boiler/air heater design data is required:

- Fuel Analysis for Coal, Oil, or Gas
- Ambient Conditions
- Reference Values—These are the conditions that the test results are corrected to for comparison to design. Corrections to losses and credits are made in accordance with ASME PTC 4, *Fired Steam Generators*. Dry gases are recomputed using design fuel analysis and used to compute dry gas loss at standard conditions.

- Number of Water-Cooled Furnace Walls—Required for radiation loss calculation.
- Maximum Heat Input—Used for calculating radiation loss.
- If the design X-ratio for the air heaters is not available, it can be readily calculated by dividing the flue gas temperature drop (calculated using the no leakage gas outlet temperature) by the air temperature drop. A typical value is about 0.75.

Test Data

Test data necessary for calculating boiler/air heater performance include:

- Ambient Dry Bulb Temperature and Humidity
- Gas Entering Air Heater—Temperatures and oxygen levels for the flue gas entering the air heaters is entered here. One to four values may be entered. The corresponding average will be determined.
- Relevant Air Heater Data (temperature, excess oxygen, etc.)
- As-Burned Fuel Analyses (coal/oil and gas, as applicable)
- Amount of Fuel Burned
- Flue Gas Analysis
- The fuel flow values entered in the **Test Fuel Consumption** fields on the *Test Data* worksheet are primarily used for determining the radiant heat loss based on the ABMA Loss Curve and the accuracy is not critical for calculating an accurate boiler efficiency value. Be sure to select whether the flue gas analysis is on a dry basis or wet basis in cell AB16. In general, if an in-situ probe is used to determine excess oxygen, the analysis is wet. If the sample is extracted and directed through a bubbler where the water vapor in the flue gas is condensed, the analysis in considered dry.

Workbook Calculations

As noted previously, the *GPCALCS Boiler Performance Workbook* calculates boiler efficiency, air heater X-ratio, air heater gas-side efficiency, and air heater leakage. These are described below.

Boiler Efficiency

Boiler efficiency is calculated as shown below.

$$\eta_{blr} = \left(1 - \frac{L}{HHV + B}\right) \times 100\% \qquad \textbf{Equation 5-1}$$

where

η_{blr} Boiler efficiency, %

L Heat loss from boiler not absorbed by steam and water

	circuits, Btu/lb_{fuel} (see GP-BLR-001)
HHV	Fuel higher heating value, Btu/lb_{fuel}
B	Heat credits added to the boiler, Btu/lb_{fuel} (see GP-BLR-001)

Corrections to boiler efficiency include the following:

- **Air-Heater Leakage**—The flue gas exit temperature must be corrected for air-heater leakage because the leakage cools the gas leaving the air heater. If left uncorrected, the lower gas temperature results in erroneously high, calculated boiler efficiency. The result of an air heater leakage test is required to apply this correction. This is one of the most important corrections.
- **Entering Air Temperature**—Correction for the temperature of air entering the air heater is necessary because it affects the sensible heat of incoming air.

  Corrections to dry gas loss and sensible heat loss in the flash are necessary because of differences in the inlet temperature from the standard temperature. The correction is made by substituting the standard temperature for the test air inlet temperature and the corrected flue exit gas temperature into the heat loss calculations.

  Corrections for moisture in the inlet air and in the fuel for changes in inlet air temperature are necessary because it changes the enthalpy of the entering moisture. This correction is made by substituting the enthalpies at the standard inlet air temperature and corrected flue gas exit temperature into the heat loss calculations.
- **Moisture in Fuel and from Burning Hydrogen**—Corrections to moisture heat loss in the fuel and hydrogen and for changes to moisture and hydrogen in the standard coal are made by substituting the standard values for moisture and hydrogen into the heat loss calculations. Corrections for differences in carbon and sulfur in the coal are accounted for in the same way.
- **Moisture in Air**—Corrections to moisture heat loss in air for differences to moisture in the test air from standard air are made by substituting the weight of moisture per pound of fuel in the standard air into the calculations.

Air Heater Gas-Side Efficiency

Gas-side efficiency is the ratio of the gas temperature drop to the temperature head. The no-leakage exit gas temperature is used in the calculation.

Step 1: Determine the no leakage exit gas temperature.

$$T_{gnl} = T_{gl} + \frac{\%AHL\left(T_{gl} - T_{ai}\right)}{100\%}$$

Equation 5-2

where

T_{gnl}	Temperature of flue gas leaving air heater, corrected for leakage, °F
%AHL	Air heater leakage percentage of gas flow entering air heater, %
T_{gl}	Temperature of flue gas leaving air heater, measured, °F
T_{ai}	Temperature of air entering the air heater, °F

Step 2: Determine the gas-side efficiency.

$$\eta_{ah} = \left(\frac{T_{gi} - T_{gnl}}{T_{gi} - T_{ai}} \right)$$ **Equation 5-3**

where

η_{ah}	Air heater gas-side efficiency, %
T_{gi}	Temperature of flue gas entering air heater, measured, °F
T_{gnl}	Temperature of flue gas leaving air heater, corrected for leakage, °F
T_{ai}	Temperature of air entering the air heater, °F

Air Heater X-Ratio

The X-ratio is defined as the ratio of the gas temperature drop to the air temperature rise.

$$X - ratio = \left(\frac{T_{gi} - T_{gnl}}{T_{aoi} - T_{ai}} \right)$$ **Equation 5-4**

where

X-ratio	Air heater X-ratio, dimensionless
T_{gi}	Temperature of flue gas entering air heater, measured, °F
T_{gnl}	Temperature of flue gas leaving air heater, corrected for leakage, °F
T_{aol}	Temperature of air leaving air heater, measured, °F
T_{ai}	Temperature of air entering the air heater, °F

Air Heater Leakage

Air heater leakage is expressed as a percentage of gas flow entering the air heater. It is quantified using either **Equation 5-5** or **5-6.**

Oxygen Readings

$$\%AHL = \left(\frac{O_{2outlet} - O_{2inlet}}{20.9 - O_{2outlet}} \right) \times 90$$ **Equation 5-5**

where

%AHL	Air heater leakage percentage of gas flow entering air heater, %
$O_{2outlet}$	Oxygen at air heater outlet on a dry basis, measured, %
O_{2inlet}	Oxygen at air heater inlet on a dry basis, measured, %

20.9 Constant, percentage oxygen in ambient air,%
90% Empirical constant, dimensionless

Carbon Dioxide Readings

$$\%AHL = \left(\frac{CO_{2inlet} - CO_{2outlet}}{CO_{2outlet}} \right) \times 90$$ **Equation 5-6**

where

%AHL Air heater leakage percentage of gas flow entering air heater, %
CO_{2inlet} Carbon dioxide at air heater inlet on a dry basis, measured, %
$CO_{2outlet}$ Carbon dioxide at air heater outlet on a dry basis, measured, %
90 Empirical constant, dimensionless

6

Compressor Performance Workbook

Compressor Performance Workbook

This workbook calculates the compressor performance indices of compressor capacity, polytropic head, isentropic and polytropic efficiencies for air or gases, and gas power required. Calculated test values are corrected to design compressor speed and inlet conditions and then compared to design values. These performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values. To assess performance, polytropic head versus capacity should be plotted on a design compressor curve.

Measuring Compressor Performance

Compressors are used to raise the pressure of gas or air and are found in nearly every industry in a wide range of applications. Performance monitoring of compressors is accomplished by accurately measuring gas flow, compressor speed, and pressure and temperature at the suction and discharge, and then calculating efficiency and capacity. Efficiency and capacity parameters (measured and expected) can be trended over time to detect changes in compressor condition.

What You'll Need

Analyzing compressor performance requires few field measurements. It may be necessary to measure the gas density or have a gas analysis that can be used to calculate molecular weight.

Design Data

The following design data is required:

- Suction Volume Flow Rate
- Suction Pressure and Temperature
- Discharge Pressure and Temperature
- Compressor Speed
- Required Power
- Motor Properties (Horsepower, Voltage, Rated Speed, Efficiency, and Power Factor)
- Gas Properties

Test Data

Test data necessary for compressor performance monitoring include:

- Ambient Conditions (Barometric Pressure, Temperature, and Relative Humidity)
- Suction Pressure and Temperature
- Discharge Pressure and Temperature
- Suction Volume Flow
- Compressor Speed
- Test Power Input

You must select the flow measurement type using either inlet conditions or reference conditions. Flow measurement poses the most difficult challenge, especially in large diameter pipes. Flows of high-capacity compressors are usually metered by measuring the differential pressure across an orifice plate, flow nozzle, or Venturi tube. This requires calculating the density of the gas from pressure and temperature measurements and the gas constituents. If the gas constituents change substantially, they can be measured using a gas chromatograph. Flows are required to calculate compressor capacity and head. The *GPCALCS Flow Metering Workbook* calculates the flow of water or steam for an orifice plate, flow nozzle, or Venturi tube (refer to **Chapter 12**).

Accurate measurement of temperatures is critical to calculated efficiencies. For example, a 10°F error in an inlet temperature measurement will result in a 6% error in calculated polytropic efficiency. Similarly, a 10 psi error in an inlet pressure measurement will result in a 2.85% error in polytropic efficiency.

For calculation of compressor capacity and head, the molecular weight of the gas entering the compressor must be known. This requires that due consideration be given to the level of monitoring desired and the outcome expected given the field information available.

You must select the method used to determine the test power input. These are three methods:

- **Method 1:** Measure the motor power input.
- **Method 2:** Calculate the power input from the measured motor current.
- **Method 3:** Measure the mechanical compressor input.

Workbook Calculations

As noted previously, the *GPCALCS Compressor Performance Workbook* calculates compressor capacity, polytropic head, isentropic and polytropic efficiencies for air or gases, and gas power required. These are described below.

Isentropic Efficiency

Isentropic efficiency relates the actual work done to the gas to the ideal work required, and is expressed as the ratio of the ideal temperature rise to the actual temperature rise:

$$\eta_{ci} = \frac{T'_{02} - T_{01}}{T_{02} - T_{01}} x100\% \qquad \textbf{Equation 6-1}$$

where

η_{ci}	Isentropic compressor efficiency, %
T'_{02}	Ideal stage outlet temperature, °R
T_{02}	Actual stage outlet temperature, °R
T_{01}	Actual stage inlet temperature, °R

An alternative expression for isentropic efficiency uses pressure and temperature measurements made at the compressor inlet and outlet:

$$\eta_{ci} = \frac{T_{01}\left(\left(\frac{P_{02}}{P_{01}}\right)^{\frac{k-1}{k}} -1\right)}{T_{02} - T_{01}} \times 100 \qquad \textbf{Equation 6-2}$$

where

η_{ci}	Isentropic compressor efficiency, %
P_{02}	Actual stage outlet pressure, psia
P_{01}	Actual stage inlet pressure, psia
T_{02}	Actual stage outlet temperature, °R
T_{01}	Actual stage inlet temperature, °R
k	Ratio of specific heats, dimensionless

The above two equations yield the same result.

Polytropic Efficiency

Polytropic efficiency or *small-stage efficiency* is defined as the isentropic efficiency of an elemental stage in the compressor such that it is constant throughout the whole compressor and is calculated as follows:

$$\eta_{cp} = \left(\frac{k-1}{k}\right)\frac{\ln\left(\frac{P_{02}}{P_{01}}\right)}{\ln\left(\frac{T_{02}}{T_{01}}\right)} x100\% \qquad \textbf{Equation 6-3}$$

where

η_{cp}	Polytropic compressor efficiency, %
P_{02}	Actual stage outlet pressure, psia
P_{01}	Actual stage inlet pressure, psia
T_{02}	Actual stage outlet temperature, °R
T_{01}	Actual stage inlet temperature, °R
k	Ratio of specific heats, dimensionless

Polytropic Head

Compressor performance may be expressed as polytropic head. As stated previously, compressors raise the pressure of gas or air. The pressure capability of the compressor is described by its *head capacity*, while the quantity of gas compressed is described by its *flow capacity*. Polytropic head is calculated as follows:

$$H_p = R' \ T_1 \times \frac{n}{n-1}\left(r^{\frac{n-1}{n}} - 1\right) \times \frac{z_1 + z_2}{2} \qquad \textbf{Equation 6-4}$$

where

H_P	Polytropic head, ft-lb/lb
R'	Specific gas constant, ft-lb/lb °R
n	Polytropic exponent, dimensionless
r	Ratio of compression, dimensionless
z_1	Inlet compressibility, factor, dimensionless
z_2	Outlet compressibility, factor, dimensionless

Once the actual head is known, the compressor's performance map may be consulted to determine the expected head. The compressor map is entered at the actual flow and head to determine the expected compressor speed. The actual head and capacity are then adjusted using the similarity laws, as follows:

$$H_e = H_a\left(\frac{N_e}{N_a}\right)^2 \qquad \textbf{Equation 6-5}$$

$$Q_e = Q_a \left(\frac{N_e}{N_a} \right)$$ **Equation 6-6**

where

H_e Expected head, ft
H_a Actual head, ft
Q_e Expected capacity, cfm
Q_a Actual capacity, cfm
N_e Expected speed, rpm
N_a Actual speed, rpm

The expected compressor head and capacity may be compared to the actual head and capacity to determine the magnitude of the compressor deficiency.

Gas Power Required

It is sometimes useful to know the power required to compress the gas flowing through the compressor to the desired discharge pressure. This is calculated from measurements of flow and inlet and outlet pressure and temperature, as follows:

$$HP_T = \frac{WH_p}{33{,}000\eta_{cp}}$$ **Equation 6-7**

where

HP_T Theoretical gas power, hp
W Weight flow, lb/min
H_p Polytropic head, ft-lb/lb
η_{cp} Polytropic compressor efficiency, %

7

Condenser Performance Workbook

Condenser Performance Workbook

This workbook calculates the condenser performance indices of expected condenser pressure for the test conditions, cleanliness factor, terminal temperature difference, and condenser heat load (duty). Expected performance is calculated using a model of the condenser based on the HEI standard. Condenser heat load is calculated using one of four different methods. Circulating water flow is either measured or calculated from condenser heat load and measured circulating water temperature rise. Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Measuring Condenser Performance

The main purpose of the condenser is to reduce the pressure at the main turbine and, therefore, make more of the energy in the steam available to do work in the turbine. The efficiency of the turbine and thus the entire plant is strongly affected by the pressure at the turbine exhaust. Condenser performance is a function of how well it transfers the heat of the condensing steam to the circulating water.

What You'll Need

Condenser design data required by the GPCALCS condenser model is found on the design data sheet or often on the original performance curves supplied by the manufacturer.

Design Data

The following condenser design data is required:

- Circulating Water Flow
- Effective Tube Length
- Number of Tubes
- Number of Passes
- Tube Outside Diameter
- Tube Size Constant
- Circulating Water Flow
- Tube Material Constant
- Cleanliness Factor

You must select the method used to determine the tube surface area to calculate the condenser heat load. There are two Surface Area Calculation Methods:

- **Option 1:** Enter a value for surface area.
- **Option 2:** Calculate the surface area based on the design tube information.

Test Data

Test data necessary for calculating condenser performance include:

- Condenser Pressure
- CW Inlet Temperature
- CW Outlet Temperature
- Hotwell Temperature
- Number of Plugged Tubes
- Circulating Water Flow

You must specify the method used to calculate the condenser heat load. There are four Condenser Duty Methods:

- **Method 1:** Enter a value for condenser duty.
- **Method 2:** Calculate the duty based on circulating water flow and temperature rise. If you choose this method, you must enter a value for circulating water flow on the worksheet.
- **Method 3:** Calculate the duty based on steam flow to the condenser and its latent heat.
- **Method 4:** Calculate the duty based on a turbine cycle heat balance.

You must also specify the method used to determine circulating water flow. There are two Circulating Water Flow Methods:

- **Method 1:** Enter a value for circulating water flow.
- **Method 2:** Calculate the flow based on condenser duty.

Note *If Condenser Duty Method 2 is selected, Circulating Water Flow Method 2 cannot be used. The circulating water flow, listed under Method 2, references a calculated value and cannot be changed.*

Workbook Calculations

As noted previously, the *GPCALCS Condenser Performance Workbook* calculates expected condenser pressure for the test conditions, cleanliness factor, terminal temperature difference, and condenser heat load. These are described below.

Expected Condenser Pressure

The following calculation steps are used to compute the expected condenser shell pressure.

Step 1: Calculate the average tube water velocity.

$$V = \frac{N_p GPM_{cwt}}{N_t GPM_{tube}}$$ **Equation 7-1**

where

V	Average tube velocity, fps
N_p	Number of passes
N_t	Number of tubes
GPM_{cwt}	Test circulating water flow, gpm
GPM_{tube}	Circulating water flow per tube at 1 fps, gpm/fps

Step 2: Calculate the general heat transfer relationship.

$$K = \frac{L_t N_p F_a F_b F_f F_c}{\sqrt{V}}$$ **Equation 7-2**

where

K	General heat transfer relationship, dimensionless
L_t	Effective tube length, ft
N_p	Number of passes
F_a	Tube size constant, dimensionless
F_b	Tube material constant, dimensionless
F_f	Circulating water inlet correction factor, dimensionless
F_c	Tube cleanliness factor, dimensionless
V	Average tube velocity, fps (see **Equation 7-1**)

Step 3: Calculate the ratio of temperature rise to initial temperature difference.

$$R = 1 - \frac{1}{e^K}$$ **Equation 7-3**

where

R Ratio of temperature rise to initial temperature difference, dimensionless

e Constant, 2.71828

K General heat transfer relationship, dimensionless (see **Equation 7-2**)

Step 4: Calculate the circulating water temperature rise.

$$TR = \frac{Q_{cond}}{500GPM_{cwt}}$$ **Equation 7-4**

where

TR Circulating water temperature rise, °F

Q_{cond} Condenser heat duty, Btu/h

GPM_{cwt} Test circulating water flow, gpm

Step 5: Calculate the initial temperature difference.

$$ITD = \frac{TR}{R}$$ **Equation 7-5**

where

ITD Initial temperature difference, °F

TR Circulating water temperature rise, °F

R Ratio of temperature rise to initial temperature difference, dimensionless

Step 6: Calculate the terminal temperature difference.

$$TTD = ITD - TR$$ **Equation 7-6**

where

TTD Terminal temperature difference, °F

ITD Initial temperature difference, °F

TR Circulating water temperature rise, °F

Step 7: Calculate the shell saturation temperature. If the terminal temperature difference determined in **Step 6** is greater than or equal to 5°F, then **Equation 7-7** is used to calculate the saturation temperature.

$$T_{sat} = ITD + T_{cwi}$$ **Equation 7-7**

where

T_{sat} Shell saturation temperature, °F

ITD Initial temperature difference, °F

T_{cwi} Circulating water inlet temperature, °F

If the terminal temperature difference is less than 5°F, then **Equation 7-8** is used to calculate the saturation temperature per HEI standards.

$$T_{sat} = TR + T_{cwi} + 5 \quad \textbf{Equation 7-8}$$

where

T_{sat} Shell saturation temperature, °F

TR Circulating water rise, °F

T_{cwi} Circulating water inlet temperature, °F

Step 8: The expected condenser pressure, P_d at T_{sat}, is determined from the ASME steam tables.

Tube Cleanliness Factor

The test tube cleanliness factor is calculated as shown below.

$$F_{ct} = \frac{U_t}{U_d} \quad \textbf{Equation 7-9}$$

where

F_{ct} Test cleanliness factor, dimensionless

U_t Test overall heat transfer coefficient, Btu/lb °F

U_d Design overall heat transfer coefficient, Btu/lb °F

Note

Tube cleanliness is very sensitive to condenser pressure measurement error. For example, a 0.1 $inHg_a$ error in pressure measurement results in a 6 to 7% error in tube cleanliness. Therefore, condenser cleanliness values computed from test data must be considered along with other indicators of performance.

Terminal Temperature Difference

Terminal Temperature Difference, TTD, is an indication of heat transfer effectiveness. It is the difference between the saturation temperature corresponding to the condenser shell pressure and the circulating water outlet temperature. TTD is calculated as shown below.

$$TTD_t = T_{sat} - T_{cwo} \quad \textbf{Equation 7-10}$$

where

TTD_t Test terminal temperature difference, °F

T_{sat} Saturation temperature at test shell pressure, °F

T_{cwo} Measured circulating water outlet temperature, °F

Condenser Heat Load

Three independent methods can be used to calculate condenser heat load.

Method 1: Circulating Water Flow. If circulating water flow is measured, condenser heat load is calculated, as shown below.

$$Q_{cond} = w_{cwt} c_p \left(T_{cwo} - T_{cwi}\right) \quad \textbf{Equation 7-11}$$

where

Q_{cond}	Condenser heat load, Btu/h
w_{cwt}	Test circulating water flow, lb/h
c_p	Specific heat of circulating water, Btu/lb °F
T_{cwo}	Circulating water outlet temperature, °F
T_{cwi}	Circulating water inlet temperature, °F

Method 2: Turbine Cycle Heat Balance. If a turbine cycle heat rate test is performed concurrently with the condenser test, the condenser load is calculated as shown below.

$$Q_{cond} = KW_t\left(TCHR_t - \frac{3412.142}{\eta_{gen}/100}\right)$$ **Equation 7-12**

where

Q_{cond}	Condenser heat duty, Btu/h
KW_t	Test gross generator output, kWh
$TCHR_t$	Test turbine cycle heat rate, Btu/kWh
3412.142	Constant, Btu/kWh
η_{gen}	Generator efficiency, %

Note

If a turbine test was not performed concurrently with the condenser test, the most recent full-load turbine cycle heat rate test result or design turbine cycle heat rate may be substituted into ***Equation 7-12.*** *When using this equation, condenser load will be directly affected by any error in measured feedwater flow.*

Method 3: Condensate Flow. Condenser load is estimated, as shown below.

$$Q_{cond} = w_c \times \Delta h_{ex}$$ **Equation 7-13**

where

Q_{cond}	Condenser heat duty, Btu/h
w_c	Test condensate flow less drain flow, lb/h
Δh_{ex}	Latent heat of exhaust steam (typically 970 Btu/lbm)

Controlled Extraction Turbine Performance Workbook

Controlled Extraction Turbine Performance Workbook

This workbook calculates the performance of condensing and non-condensing steam turbines typically used in combined cycle and cogeneration applications. Depending on turbine type, arrangement, and available instrumentation, performance indices of enthalpy-drop efficiency and/or steam rate are calculated and compared with design values. For controlled extraction or induction turbines, expected output and steam rate are calculated for variations in the extraction or induction flow.

Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values. Computations are performed using the techniques found in Pollard, E. V. and K. A. Drewry, *Estimating Performance of Automatic-Extraction Turbines*, General Electric Co., GER-2685.

Measuring Controlled Extraction Turbine Performance

Extraction turbines differ in two major respects from straight condensing or non-condensing turbines. Certain areas in the steam path are designed with enlarged sections so that large quantities of steam can be extracted for process requirements. Additional control devices and linkages have been added to maintain extraction pressure, load, and flow control automatically.

Turbine performance is affected by conditions both internal and external to the turbine casing. Internal conditions that decrease performance include wear and damage to buckets, diaphragms, and seals. Enthalpy-drop efficiency tests for the controlled extraction, uncontrolled extraction, and non-condensing sections of the turbine can often detect these conditions. External conditions that decrease performance include boiler performance, extraction requirements, auxiliary steam supply requirements, condenser performance, and heater drain disposition. For test purposes, most external conditions can be eliminated either by appropriate isolation practices or by correction factors applied during engineering calculations.

The performance curve method of evaluating turbine performance uses either the steam map data provided by the manufacturer or data obtained using the Estimating Extraction Performance Method given in Pollard, E. V. and K. A. Drewry, *Estimating Performance of Automatic-Extraction Turbines*, General Electric Co., GER-2685. The performance curve relates the throttle flow to the output that will be produced at a set of constant extraction (or admission) flow lines. The expected generation at test conditions is plotted on the curve and compared to actual test generation.

What You'll Need

Assessing the expected performance (output for given throttle and extraction flows) requires either a "steam map" provided by the turbine manufacturer, or certain design operating parameters that can be used to estimate this steam map. Correcting the expected performance to design conditions requires the use of correction curves supplied by the manufacturer.

Assessing turbine section enthalpy-drop efficiency requires a turbine cycle heat balance to provide design data and test data of temperature and pressure.

Design Data

The following turbine design data is required:

- Maximum Rated Output
- Throttle Pressure and Temperature
- Exhaust Pressure
- Controlled Extraction Pressure
- Maximum Controlled Extraction Flow
- Design Uncontrolled Extraction Flow

You must select the method used to determine expected turbine performance. There are two options:

- **Option 1:** Use Manufacturer's Steam Map data.
- **Option 2:** Calculate the expected performance.

Test Data

Test data necessary for calculating turbine performance and enthalpy-drop efficiency include:

- Gross Generation
- Throttle Flow, Pressure, and Temperature
- Controlled Extraction flow, Pressure, and Temperature
- Uncontrolled Extraction flow, Pressure, and Temperature
- Exhaust Pressure
- Exhaust Temperature (non-condensing)
- Barometric Pressure

Test data is corrected to design conditions using the correction factors supplied in the manufacturer's thermal kit.

Workbook Calculations

The *GPCALCS Controlled Extraction Turbine Performance Workbook* calculates the generation expected at design conditions, based on the test throttle flow, test uncontrolled extraction flow (if applicable), and test-controlled extraction or admission flow. Using manufacturer's corrections for variations in operating conditions from design (e.g., throttle pressure, throttle temperature, etc.). The workbook also calculates the generation that would be expected at current operating conditions. The results of these calculations are presented in a report and depicted graphically on a copy of the steam map.

In addition, the *GPCALCS Controlled Extraction Turbine Performance Workbook* calculates turbine section enthalpy-drop efficiencies, actual and design. These are described below.

Enthalpy-Drop Efficiency

The enthalpy-drop efficiency test measures how much of the available energy in the steam supplied to the turbine is used to produce power. This test can be applied to any section of the turbine that operates entirely in the superheated steam region. For a controlled extraction turbine, this typically includes from the throttle to the uncontrolled extraction, if there is one, and from the throttle to the controlled extraction. If the turbine is a non-condensing turbine, this performance measure can also be calculated from throttle to exhaust. It is calculated as follows:

$$\eta_{sect} = \frac{h_{thr} - h_{ep}}{h_{thr} - h_{epi}} x100\%$$

Equation 8-1

where

η_{sect}	Section enthalpy-drop efficiency, %
h_{thr}	Steam enthalpy at throttle pressure and temperature, Btu/lb
h_{ep}	Steam enthalpy at expansion endpoint of interest, i.e., uncontrolled extraction, controlled extraction, or turbine exhaust, Btu/lb
h_{epi}	Steam enthalpy at expansion endpoint pressure and throttle entropy, Btu/lb

9

Cooling Tower Performance Workbook

Cooling Tower Performance Workbook

This workbook calculates cooling tower capability using the Performance Curve Method in general accordance with the CTI Code ATC-105, *Acceptance Test Codes for Water-Cooling Towers*, published by the Cooling Tower Institute and ASME PTC 23, *Atmospheric Water-Cooling Equipment*. Based on ambient wet bulb temperature, the expected cold-water temperature for the given heat loading is predicted. Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Measuring Cooling Tower Performance

A cooling tower cools the incoming water by a combination of heat and mass transfer. Water returned to the tower is sprayed or splashed over fill, which breaks up the water and exposes a very large surface area of the water to the air. In a typical power plant cooling tower, the air flows upward through the tower counter to the water flow direction, either due to convection (natural draft tower) or to cooling tower fans (mechanical draft tower). A portion of the water is evaporated into the air, with the necessary latent heat being transferred from the remaining water, thus lowering its temperature. There is also some sensible heat transfer from the water to the air. The driving force for this heat and mass transfer process is the difference between the wet bulb temperature of the entering air and the temperature of the water.

For the performance curve method of evaluating cooling tower performance, the tower manufacturer must provide a family of performance curves relating cold water temperature to wet bulb temperature, cooling range, and circulating water flow. Each curve in the set represents a given cooling range; a minimum of three ranges must be shown — 80%, 100%, and 120%. Each curve relates the entering air wet bulb temperature to the cold-water temperature that will be produced for that cooling range. Three sets of curves must be provided, applying to 90%, 100%, and 110% of the design circulating water flow rate.

The design performance curves are cross plotted at test conditions to determine the predicted water flow that could be cooled through the test range with design tower performance. The test circulating water flow, adjusted for variation in fan power required from design, is compared with this to determine tower capability.

What You'll Need

Design Data

The following design data is required:

- Manufacturer's performance curve data for 90%, 100%, and 110% of the design water circulation rate. Each set should be presented as a set of wet-bulb temperatures as abscissa versus cold-water temperature as ordinate, with cooling range as parameter. In addition to the design range curve data, bracketing range curve data of approximately 80% and 120% of design (to the nearest °F) should be provided.
- Number of Cells
- Fan Speed
- Shaft Power
- Circulating Water Flow
- Design Point Wet Bulb Temperature
- Design Point Range
- Design Point Cold Water Temperature

Test Data

Test data necessary for calculating cooling tower performance include:

- Inlet Air Wet Bulb Temperature
- Hot Water Temperature
- Cold Water Temperature
- Circulating Water Flow
- Fan Motor Power Input
- Dry Bulb Temperature

- Barometric Pressure
- Wind Speed
- Wind Direction

You must select the method used to determine the test fan power input. There are two methods:

- **Method 1:** Measure the motor power input.
- **Method 2:** Calculate the power input for the measured motor voltage, current, and power factor.

Workbook Calculations

The *GPCALCS Cooling Tower Performance Workbook* calculates cooling range, approach, test fan power, adjusted test circulating water flow rate, predicted circulating water flow rate, predicted cold water temperature, and cooling tower capability. These are described below.

Cooling Range

The cooling tower cooling range is calculated as follows:

$$R = T_1 - T_2$$ **Equation 9-1**

where

R	Cooling range, °F
T_1	Hot water temperature, °F
T_2	Cold water temperature, °F

Approach

The cooling tower approach is calculated as follows:

$$Approach = T_3 - T_4$$ **Equation 9-2**

where

T_3	Wet bulb temperature of inlet air, °F
T_4	Outlet water temperature, °F

Test Fan Power

Test fan power is calculated as follows:

$$HP_t = \frac{\eta_{mtr} KW_t}{0.746}$$ **Equation 9-3**

where

HP_t	Measured (test) fan power, hp
η_{mtr}	Motor manufacturer's stated efficiency, %
KW_t	Test fan motor power input, kW

Adjusted Test Circulating Water Flow Rate

The measured (test) circulating water flow rate is adjusted for deviations in fan power from design, as follows:

$$L_t = L_c \left(\frac{HP_d}{HP_t}\right)^{\frac{1}{3}}$$ **Equation 9-4**

where

L_t Adjusted test circulating water flow, gpm
L_c Measured test circulating water flow rate, gpm
HP_d Design fan power, hp
HP_t Test fan power, hp

Predicted Circulating Water Flow Rate

From the test wet-bulb temperature, a cross plot relating cooling range to cold water temperature is prepared. From this graph, the predicted circulating water flow rate at the test cold water temperature is determined.

Predicted Cold Water Temperature

From the test wet-bulb temperature and cooling, a cross plot relating cold water temperature to circulating water flow is prepared. From this graph, the predicted cold-water temperature at the predicted circulating water flow rate is determined.

Cooling Tower Capability

Cooling Tower capability is calculated, as follows:

$$Q = \frac{L_t}{L_p} \times 100\%$$ **Equation 9-5**

where

Q Cooling tower capability, %
L_t Adjusted test circulating water flow, gpm
L_p Predicted circulating water flow, gpm

10

Fan Performance Workbook

Fan Performance Workbook

This workbook calculates the fan performance indices of brake horsepower, total fan pressure, fan capacity, and static and total efficiencies. Calculated test values are compared to design values based on flow, rated speed, and corrected to design fan speed and inlet temperature. Computations are performed in accordance with the ASME Performance Test Code PTC 11, *Fans*. Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Measuring Fan Performance

A fan moves a quantity of air by adding sufficient energy to the air stream to start motion and overcome resistance to flow. Physically, the fan consists of a bladed rotor or impeller that does the actual work, and a housing to collect and direct the air or gas discharged by the impeller. The power required depends on the volume of gas moved per unit time, the pressure differences across the fan, and the efficiency of the fan and its drive.

In general, it is considered impractical to conduct efficiency tests on large power plant fans in the field because ductwork configuration issues (bends, dampers, structural arrangements at the inlet and discharge, etc.) lead to inconsistent test data. For this reason, the manufacturer is generally relied upon to supply test data and performance curves for a given fan design.

What You'll Need

Analyzing fan performance requires a significant amount of test data.

Design Data

The following design data is required:

- Fan Capacity
- Fan Static Pressure
- Rated Fan Inlet Temperature
- Rated Fan Speed
- Required Brake Horsepower
- Drive Motor Properties (Horsepower, Voltage, Rated Speed, Efficiency, and Power Factor)
- Fan Inlet and Outlet Arrangement

Test Data

Test data necessary for fan performance monitoring include:

- Ambient Conditions (Barometric Pressure, Temperature, and Relative Humidity)
- Inlet Static Pressure and Temperature
- Outlet Static Pressure and Temperature
- Inlet and Outlet Duct Cross Sectional Areas
- Fan Speed
- Power Input
- Fan Capacity

You must select the method used to determine the volumetric flow rate for the fan capacity calculation. There are two methods:

- **Method 1:** Measure the pressure drop across a flow meter.
- **Method 2:** Calculate the volumetric flow rate from a velocity pressure traverse taken from a Pitot static tube.

You must select the method used to determine the test power input. There are three methods:

- **Method 1:** Measure the motor power input.
- **Method 2:** Calculate the power input from the measured motor current.
- **Method 3:** Measure the mechanical fan power input.

Workbook Calculations

As noted previously, the *GPCALCS Fan Performance Workbook* calculates brake horsepower, total fan pressure, fan capacity, and static and total efficiencies. These are described below.

Brake Horsepower

Three independent methods can be used to determine brake horsepower.

Method 1: Measure the motor power input.

$$HP = \frac{1000W\eta_m}{745.7}$$ **Equation 10-1**

where

HP	Motor power input, hp
W	Motor power, kW
η_m	Motor efficiency, %

Method 2: Calculate the power input from the measured motor current.

$$HP = \frac{\sqrt{3}VIPF_m\eta_m}{745.7}$$ **Equation 10-2**

where

HP	Motor power input, hp
V	Motor voltage, V
I	Motor current, amps
PF_m	Motor power factor, dimensionless
η_m	Motor efficiency, %

Method 3: Measure the actual mechanical fan power input.

Total Fan Pressure

Total fan pressure is expressed as follows:

$$P_t = P_o - P_i$$ **Equation 10-3**

where

P_t	Total fan pressure, inH_2O
P_o	Total pressure at fan outlet, inH_2O
P_i	Total pressure at fan inlet, inH_2O

Fan Capacity

Fan capacity is expressed as follows:

$$Q = \frac{Q_x\rho_x}{\rho}$$ **Equation 10-4**

where

Q	Fan capacity, cfm
Q_x	Volumetric flow rate at plane x, cfm
ρ_x	Air density at plane x, lbm/ft^3
ρ	Fan air density, lbm/ft^3

Volumetric flow rate can be determined by a direct measurement of the pressure drop across a flow meter or by a velocity-pressure traverse taken with a Pitot static tube. If a Pitot static tube method is used, the volumetric flow rate is found using **Equation 10-5**.

$$Q_x = 1.097 A_x \sqrt{\frac{P_{vx}}{\rho_x}}$$ **Equation 10-5**

where

Q_x	Volumetric flow rate at plane x, cfm
A_x	Area at plane x, ft^2
P_{vx}	Velocity pressure at plane x, in w.g.
ρ_x	Air density at plane x, lbm/ft^3

Fan Total Efficiency

Fan total efficiency is expressed as the ratio of the fans power output to the fan power input, or:

$$\eta_t = \frac{Q P_t K_p}{6356 HP}$$ **Equation 10-6**

where

η_t	Fan total efficiency, %
Q	Fan capacity, cfm
P_t	Fan total pressure, inH_2O
K_p	Compressibility factor, dimensionless
HP	Fan power input, hp

Fan Static Efficiency

Fan static efficiency is expressed as:

$$\eta_s = \frac{\eta_t P_s}{P_t}$$ **Equation 10-7**

where

η_s	Total static efficiency, %
η_t	Total efficiency, %
P_s	Fan static pressure, inH_2O
P_t	Fan total pressure, inH_2O

11

Feedwater Heater Performance Workbook

Feedwater Heater Performance Workbook

This workbook calculates the feedwater heater performance indices of terminal temperature difference, drain cooler approach, and feedwater temperature rise. These values, along with extraction flow, are compared to expected values predicted using a detailed model of the feedwater heater[1]. Like the condenser workbook, the number of plugged tubes can be readily entered into the original design data to obtain expected performance values for off-design operation. Calculations are performed using the techniques given in ASME Performance Test Code 12.1, *Closed Feedwater Heaters*. Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and predicted values.

Measuring Feedwater Heater Performance

Feedwater heaters transfer heat from extraction steam to the feedwater that flows to the boiler to increase boiler efficiency, decrease turbine cycle heat rate, and improve overall plant efficiency. Changes in performance greatly influence boiler and turbine cycle efficiencies.

Turbine cycle heat rate is more directly impacted by feedwater heater performance. Poor heat transfer within the heater results in less extraction-

[1] *The GPCALCS Feedwater Heater Performance Workbook predicts performance of an existing feedwater heater design at off-design boundary conditions (inlet water flow, supply pressure, inlet temperature, etc.). Note that GPCALCS is not intended for studying feedwater heater design changes.*

steam feedwater heating. This causes an increase in the electrical output of the steam turbine generator. The steam that would have been extracted instead passes through the entire turbine producing the additional output, but it also rejects the majority of its heat to the condenser cooling water. This same heat would have been transferred to the feedwater and retained in the turbine cycle if it were used for extraction-steam feedwater heating.

What You'll Need

The information required for the GPCALCS feedwater heater model is found on the heater design data sheets. If these are unavailable, measured performance may be compared to heater performance listed on the turbine cycle heat balance. Note that heat balances often assume constant heater terminal temperature differences and drain cooler approaches. In this case, use the full load heat balance and conduct the tests at a comparable load point.

Design Data

The following design data is required for the feedwater heater model:

- Feedwater Inlet Flow, Pressure, and Temperature
- Feedwater Outlet Temperature
- Extraction Steam Flow, Pressure, and Temperature
- Inlet Drains Flow
- Outlet Drains Temperature
- Duty
- Surface Area
- Heat Transfer Coefficient
- Shell-Side Pressure Drop
- Tube Fouling Factor (Shell-Side and Water-Side)
- Log Mean Temperature Difference
- Tube Properties (Number of Tubes, Thermal Conductivity, OD, ID, and Feed-Side Pressure Drop)
- Design Barometric Pressure

Test Data

Test data necessary for calculating feedwater heater performance include:

- Feedwater Inlet Flow, Pressure, and Temperature
- Feedwater Outlet Temperature
- Extraction Steam Pressure and Temperature
- Inlet Drains Flow, Pressure, and Temperature
- Outlet Drains Flow and Temperature
- Barometric Pressure

Workbook Calculations

As noted previously, the *GPCALCS Feedwater Heater Performance Workbook* calculates terminal temperature difference, drain cooler approach, and feedwater temperature rise. These performance parameters are described below.

Terminal Temperature Difference

Terminal temperature difference, TTD, is defined as the difference between the saturation temperature corresponding to the steam inlet pressure and the feedwater outlet temperature.

$$TTD = T_{sat} - T_{fo}$$ **Equation 11-1**

where

TTD Terminal temperature difference, °F

T_{sat} Saturation temperature corresponding to the steam inlet pressure, °F

T_{fo} Feedwater temperature leaving heater, °F

Drain Cooler Approach

Drain cooler approach, DCA, is defined as the temperature difference between the condensate leaving the feedwater heater and the feedwater entering the heater.

$$DCA = T_{do} - T_{fi}$$ **Equation 11-2**

where

DCA Drain cooler approach, °F

T_{do} Drains temperature leaving heater, °F

T_{fi} Feedwater temperature entering heater, °F

Feedwater Temperature Rise

The feedwater temperature rise is defined as the temperature difference between the feedwater leaving and entering the heater.

$$TR = T_{fo} - T_{fi}$$ **Equation 11-3**

where

TR Feedwater temperature rise, °F

T_{fo} Feedwater temperature leaving heater, °F

T_{fi} Feedwater temperature entering heater, °F

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Flow Metering Workbook

Flow Metering Workbook

This workbook calculates the rate of flow of water or steam from measurements of static pressure, temperature, and differential pressure in accordance with ASME MFC-3M-1989. It only applies to pressure difference devices in which the flow remains turbulent and subsonic throughout the measuring section, is steady or varies only slowly with time, and the fluid is considered single-phased. It assumes the device has been properly calibrated before use. Calculations are provided for orifice plates, flow nozzles, and Venturi tubes. Important performance parameters are automatically displayed and printed in a concise report that displays design, test, and calculated values.

Measuring Flow

A flow meter is a pressure difference device that determines the quantity of fluid (weight or volume) per unit time that passes a given cross section. A flow meter is installed into a pipeline in which a flowing fluid fills the pipe. The device causes a static pressure difference between the upstream and the throat or downstream side of the element. This pressure drop can be brought about by changes in kinetic energy, skin friction, or form friction. The flow rate can be determined from the measured value of this pressure difference and from knowledge of the characteristics of the flowing fluid, as well as the circumstance under which the element is being used. A general equation resulting from an energy balance can be derived to relate flow and pressure drop.

Three types of devices are considered:

- **Orifice Plate**—Consists of a flat plate with a centrally drilled hole beveled to a sharp edge. The drilled plate is inserted perpendicularly to the flow direction and the fluid passes through the hole.
- **Flow Nozzle**—Consists of a convergent inlet connected to a cylindrical section generally called the throat.
- **Venturi Tube**—Consists of a cylindrical entrance section, followed by a convergent inlet connected to a cylindrical section called the throat and a conical expanding section called the divergent. If the convergent inlet is conical, the element is called a classical Venturi tube.

What You'll Need

Determining the rate of the fluid flowing requires knowing the geometry and method of use for the orifice plate, nozzle, or Venturi tube when it is inserted in a pipe running full.

Design Data

The following orifice plate design data is required:

- Bore Diameter of Pipe
- Diameter of Orifice
- Pipe Material
- Orifice Material
- Diameter Ratio
- Measurement Reference Temperature
- Orifice Tap Arrangement (Flange, D or D/2 Taps)

The following flow nozzle design data is required:

- Bore Diameter of Pipe
- Diameter of Flow Nozzle Throat
- Pipe Material
- Flow Nozzle Material
- Diameter Ratio
- Measurement Reference Temperature
- Nozzle Tap Arrangement (Wall or Throat Taps)

The following Venturi tube design data is required:

- Diameter of Entrance Section
- Diameter of Venturi Throat
- Venturi Tube Material
- Venturi (Inlet) Style (Fabricated, Machined, or Rough Cast)
- Divergent Angle
- Measurement Reference Temperature

Test Data

Test data necessary for determining fluid flow include:

- Static Pressure (Upstream or Downstream)
- Differential Pressure
- Temperature at Flowing Conditions
- Fluid State (Steam or Water)
- Specific Heat Ratio (for steam)

Workbook Calculations

As noted previously, the *GPCALCS Flow Metering Workbook* calculates the rate of flow of water or steam passing through a pressure difference device, as described below. It is necessary to state whether the mass rate of flow, expressed in mass per time unit, or the volume rate of flow, expressed in volume per time unit, is being used.

Mass Rate of Flow

The mass of fluid passing through the orifice or throat per unit of time can be determined for an upstream measurement by the following equation:

$$q_m = 0.09970190 C Y_1 d^2 \sqrt{\frac{h_w \rho_{f1}}{1-\beta^4}}$$ **Equation 12-1**

For a downstream measurement, the mass flow can be determined by the following equation:

$$q_m = 0.09970190 C Y_1 d^2 \sqrt{\frac{h_w \rho_{f2}}{1-\beta^4}}$$ **Equation 12-2**

where

q_m	Mass rate of flow, lbm/s
C	Discharge coefficient (see E**quation 12-3** for orifice plates, **Equation 12-10** for flow nozzles, or **Equations 12-13** and **12-14** for Venturi tubes)
Y_1	Expansion factor (see **Equation 12-8** for orifice plates or **Equation 12-11** for flow nozzles and Venturi tubes)
d	Diameter of orifice or throat of primary device, in
h_w	Differential pressure, inH_2O
ρ_f	Density of flowing fluid, lbm/ft^3 (subscript 1 refers to upstream conditions and subscript 2 refers to downstream conditions)
β	Diameter ratio, dimensionless = d/D
D	Upstream internal pipe diameter at flowing conditions, in

Volume Rate of Flow

The volume of fluid passing through the orifice or throat per unit of time can be determined by the flowing equation:

$$q_v = q_m / \rho_f = q_m / \rho_b$$ **Equation 12-3**

where

q_v Volume rate of flow, fps
q_m Mass rate of flow, lbm/s
ρ_f Density of flowing fluid, lbm/ft^3
ρ_b Density of fluid at base conditions, lbm/ft^3

Orifice Plate Coefficients

The discharge coefficient for an orifice plate is calculated, as follows:

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0900L_1\beta^4\left(1-\beta^4\right)^{-1} - 0.0337L_2'\beta^3 + 91.71\beta^{2.5}R_D^{-0.75}$$ **Equation 12-4**

where

C Discharge coefficient (see **Equations 12-5** through **12-7** for specific tap arrangements)
β Diameter ratio, dimensionless
L_1 Dimensionless correction for upstream tap location = l_1D^{-1}, measured from the upstream face
l_1 Pressure tap spacing from upstream orifice plate, in
L_2 Dimensionless correction for downstream tap location = l_2D^{-1}, measured from downstream face
l_2 Pressure tap spacing from downstream orifice plate, in
L_2' Dimensionless correction for downstream tap location, measured from downstream face, = $(l_2 - E)D^{-1}$
E Orifice plate thickness, in
R_D Reynolds number at upstream internal pipe diameter = $U_1D/12v$
U_1 Mean axial velocity of the fluid in the pipe, fps
v Kinematic viscosity of the fluid = μ/ρ, ft^2/s
μ Absolute viscosity of the fluid, lbm/ft-s
ρ Density of flowing fluid, lbm/ft^3

For flange taps: $D \geq 2.3$ in, $L_1 = L_2'$

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0900D^{-1}\beta^4\left(1-\beta^4\right)^{-1} - 0.0337D^{-1}\beta^3 + 91.71\beta^{2.5}R_D^{-0.75}$$ **Equation 12-5**

For flange taps: 2 in < D < 2.3 in, $L_1 = 0.4333$, $L_2' = D^{-1}$

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0390\beta^4\left(1-\beta^4\right)^{-1} - 0.0337D^{-1}\beta^3 + 91.71\beta^{2.5}R_D^{-0.75}$$ **Equation 12-6**

For D and D/2taps: $L_1 = 0.4333,\ L_2' = 0.47$

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0390\beta^{4}\left(1-\beta^{4}\right)^{-1}$$

$$-0.01584\beta^{3} + 91.71\beta^{2.5}R_D^{-0.75}$$ **Equation 12-7**

The upstream and downstream expansion factors for an orifice plate are calculated, as follows:

$$Y_1 = 1-\left(0.41+0.35\beta^4\right)\frac{h_w}{27.73\kappa p_1}$$ **Equation 12-8**

where

Y_1 Upstream expansion factor, dimensionless
β Diameter ratio, dimensionless
h_w Differential pressure, inH_2O
κ Dimensionless isentropic exponent = c_p/c_v
c_p Specific heat at constant pressure, Btu/lbm °F
c_v Specific heat at constant volume, Btu/lbm °F
p_1 Static pressure of flowing fluid at upstream pressure tap, lbf/in^2

$$Y_2 = \sqrt{1+\frac{h_w}{27.73p_2}} - \left(0.41+0.35\beta^4\right)\frac{h_w}{27.73\kappa p_2\sqrt{1+\frac{h_w}{27.73p_2}}}$$ **Equation 12-9**

where

Y_2 Downstream expansion factor, dimensionless
β Diameter ratio, dimensionless
h_w Differential pressure, inH_2O
κ Dimensionless isentropic exponent = c_p/c_v
p_1 Static pressure of flowing fluid at upstream pressure tap, lbf/in^2

Flow Nozzle Coefficients

The wall tap nozzle discharge coefficient for an orifice plate is calculated, as follows:

$$C = 0.9975 - 0.00653\left(10^6\beta/R_D\right)^{0.5}$$ **Equation 12-10**

with the following limitations:

$4\ in \leq D \leq 30\ in$
$0.50 \leq \beta < 0.80$ *(for high beta ratio nozzle)*
$0.20 \leq \beta < 0.50$ *(for low beta ratio nozzle)*
$10^4 \leq R^D \leq 6x10^6$
$p_2/p_1 \geq 0.75$

The throat tap nozzle discharge coefficient for a flow nozzle is given in ANSI/ASME PTC 6 and ASME PTC 19.5.

The upstream and downstream expansion factors for a flow nozzle are calculated, as follows:

$$Y_1 = \left[\left[\frac{\kappa\tau^{2/\kappa}}{\kappa-1}\right]\left[\frac{1-\beta^4}{1-\beta^4\tau^{2/\kappa}}\right]\left[\frac{1-\tau^{(\kappa-1)/\kappa}}{1-\tau}\right]\right]^{0.5}$$ **Equation 12-11**

where

Y_1	Upstream expansion factor, dimensionless
κ	Dimensionless isentropic exponent = c_p/c_v
c_p	Specific heat at constant pressure, Btu/lbm °F
c_v	Specific heat at constant volume, Btu/lbm °F
τ	Dimensionless pressure ratio = p_2/p_1
p_2	Static pressure of flowing fluid at downstream pressure tap, lbf/in^2
p_1	Static pressure of flowing fluid at upstream pressure tap, lbf/in^2

$$Y_2 = (1+\Delta p/p_2)^{0.5}\, Y_1$$ **Equation 12-12**

where

Y_2	Downstream expansion factor, dimensionless
Δp	Differential pressure, in H_2O
p_2	Static pressure of flowing fluid at downstream pressure tap, lbf/in^2
Y_1	Upstream expansion factor, dimensionless

Venturi Tube Coefficients

The discharge coefficient for a Venturi tube with a rough cast or fabricated convergent section is:

$$C = 0.984$$ **Equation 12-13**

with the following limitations:

$4 \text{ in.} \leq D \leq 48 \text{ in.}$
$0.30 \leq \beta \leq 0.77$
$2\times10^6 \leq R_D \leq 6\times10^6$

The discharge coefficient for a Venturi tube with a machined convergent section is:

$$C = 0.995$$ **Equation 12-14**

with the following limitations:

$2 \text{ in.} \leq D \leq 10 \text{ in.}$
$0.30 \leq \beta \leq 0.75$
$2\times10^5 \leq R_D \leq 2\times10^6$

The expansion factors for a Venturi tube are given in **Equations 12-11** and **12-12**.

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Gas Turbine Performance Workbook

Gas Turbine Performance Workbook

This workbook calculates the following gas turbine performance indices:

- Heat Rate
- Capacity (Power Output)
- Exhaust Mass Flow
- ISO Firing Temperature
- Compressor Efficiency (Isentropic and Polytropic)

Calculated test values are corrected to user-defined reference conditions and compared to design values. These performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Additionally, the workbook calculates fuel gas properties according to ASTM Standard D 3588, based on the entered gas composition. Alternatively, user-defined properties can be used. For gas turbines fired with distillate fuel oil, you can enter the composition and heating value from a laboratory analysis, or typical properties provided in the workbook can be used.

Measuring Gas Turbine Performance

Gas turbines are used in many applications to drive electric generators, compressors, and pumps. Gas turbine heat rate and capacity are determined from accurate measurement of fuel flow and heating value, power output, and ambient conditions of temperature, barometric pressure, and humidity. Compressor efficiency is determined from measurements of suction pressure and temperature, and discharge pressure and temperature. Each of these performance indices can be trended over time to detect changes in gas turbine condition.

What You'll Need

Analyzing gas turbine performance requires very few field measurements and correction curves to adjust observed performance to reference conditions. Reference conditions may be ISO conditions or site conditions. ISO conditions are:

- Ambient Pressure 14.696 psia
- Ambient Temperature 59°F
- Ambient Specific Humidity 0.0064 lb/lb_{air}

Design Data

The following design data at reference conditions is required:

- Heat Rate (Lower or Higher Heating Value)
- Capacity (kW or HP)
- Exhaust Mass Flow
- Exhaust Temperature
- Compression Ratio
- Number of Compressor Stages
- Reference Conditions (Temperature, Pressure, and Humidity)

The above design data should correspond to the basis of the test (for example, base load or peak load). Heat rate and power output are corrected to reference conditions using correction curves available from the gas turbine manufacturer. Corrections are normally provided for:

- Ambient Temperature
- Ambient Pressure
- Ambient Humidity
- Inlet Pressure Drop
- Exhaust Pressure Drop
- Steam or Water Injection

Correction curves may be provided based on ISO conditions or site guarantee conditions. It is easy to tell the basis of the correction curves by looking for where the correction factor is unity (1.0). It is not necessary that the basis of the curves be the same as the design reference conditions. GPCALCS will automatically correct to the basis of the curves and then adjust this performance to the design reference conditions.

Most gas turbine manufacturers have a full complement of correction curves for adjusting gas turbine performance at ISO conditions to site conditions. Site curves, if available, may be limited to certain factors.

It is rare to find compressor maps for gas turbine compressors. Therefore, GPCALCS uses the compressor design data (compression ratio and number of stages) to estimate the efficiency that should be exhibited by a "state-of-the-art" gas turbine compressor.

Test Data

Test data necessary for calculating gas turbine performance include:

- Ambient Temperature
- Barometric Pressure
- Ambient Humidity
- Fuel Heating Value (Higher or Lower)
- Power Output
- Compressor Discharge Temperature
- Compressor Discharge Pressure
- Turbine Exhaust Temperature
- Inlet and Exhaust Pressure Drops
- Any Water Injection or Steam Injection Flows

For gas turbines powering electric generators, power output is easily determined from watt-hour meters or watt transducers. For gas turbines used to drive compressors and pumps, power output is not normally available. In these cases, power output can be estimated from calculations made on the driven component. Refer to the appropriate GPCALCS workbook for methods for determining drive power requirements.

Workbook Calculations

The *GPCALCS Gas Turbine Performance Workbook* calculations are described below.

Capacity (Power Output)

A general indication of gas turbine condition is its capacity or power output. Predicted power output is:

$$GTKW_p = GTKW_d \times TCF \times APCF \times SHCF \times WICF$$ **Equation 13-1**

where

$GTKW_p$	Predicted power output, kW
$GTKW_d$	Design power output, kW
TCF	Temperature correction factor, dimensionless
APCF	Atmospheric pressure correction factor, dimensionless
SHCF	Specific humidity correction factor, dimensionless
WICF	Water injection correction factor, dimensionless

Corrected Power Output

The capacity observed during the test is adjusted to reference conditions by the use of correction curves that you enter. Each correction curve expresses the change in gas turbine power output in terms of a divisor to be applied to the test power output to adjust it to reference conditions. The product of all divisors is applied to the test power output to determine the corrected power output. This value may be compared to the design power output provided the tests were conducted at the same control setting, i.e., base load or peak load. The workbook will not correct partial load test results for comparison to design base load operation. The corrected gas turbine generator output under standard operating conditions is computed as shown below.

$$GTKW_{CORR} = \frac{GTKW_{TEST}}{CP_{AP}CP_{AH}CP_{AT}CP_{IS}}$$ **Equation 13-2**

where

$GTKW_{CORR}$	Corrected power output, kW
$GTKW_{TEST}$	Test power output, kW
CP_{AP}	Atmospheric pressure correction factor, dimensionless
CP_{AH}	Specific humidity correction factor, dimensionless
CP_{AT}	Temperature correction factor, dimensionless
CP_{IS}	Steam or water injection correction factor, dimensionless

Heat Rate

Another indication of gas turbine condition is its heat rate. Gas turbine heat rate is calculated as the ratio of fuel heat input to power output:

$$HR = \frac{Q}{P}$$ **Equation 13-3**

where

Q	Fuel heat input, Btu/h
P	Power output, kWh

Fuel heat input is determined as the product of fuel mass or volume flow and the fuel's heating value (mass or volume basis). A lower heating value is normally used by gas turbine manufacturers when stating design performance. You can use either higher or lower heating values when expressing heat rate. A fuel analysis is required to determine the fuel's heating value.

Corrected Heat Rate

The heat rate observed during the test is adjusted to reference conditions by the use of correction curves that you enter. Each correction curve expresses the change in heat rate in terms of a divisor to be applied to the test heat rate to adjust it to reference conditions. The product of all divisors is applied to the test heat rate to determine the corrected heat rate. This heat rate is compared directly to the design heat rate. The corrected heat rate under standard operating conditions is computed as shown below.

$$GTHR_{CORR} = \frac{GTHR_{TEST}}{CH_{AH}\, CH_{AT}\, CH_{IS}}$$ **Equation 13-4**

where

$GTHR_{CORR}$	Corrected heat rate, Btu/lb
$GTHR_{TEST}$	Test heat rate, Btu/lb
CH_{AH}	Specific humidity correction factor, dimensionless
CH_{AT}	Temperature correction factor, dimensionless
CH_{IS}	Steam or water injection correction factor, dimensionless

Note *Some gas turbine manufacturers provide "heat consumption" correction curves, instead of heat rate correction curves. GPCALCS can use heat consumption correction curves in combination with power output correction curves to determine the corresponding change in heat rate. If you are using heat consumption curves, be sure to check the appropriate boxes when entering these curves into GPCALCS.*

Gas Turbine Exhaust Mass Flow

The gas turbine exhaust mass flow is calculated by means of an energy balance around the gas turbine as shown below. Changes in base load gas turbine exhaust mass flow are useful for diagnosing gas turbine performance problems.

$$\dot{m}_{EXH} = \frac{Q_{FHI} + Q_{SI} - Q_{KW} - Q_{GL} - Q_{MISC}}{\left(h_{EXH} - h_{REF}\right)}$$ **Equation 13-5**

where

$\dot{m}_{EXH}$	Exhaust mass flow, lb/h
Q_{FHI}	Fuel input, consisting of the chemical energy of the fuel plus sensible heat about reference, Btu/h
Q_{SI}	Heat input from steam injection, Btu/h
Q_{KW}	Gas turbine output, Btu/h
Q_{GL}	Generator loss, Btu/lb *(this may be from a manufacturer's*

	curve or estimated)
Q_{MISC}	Heat input from steam injection, Btu/h
h_{EXH}	Enthalpy of gas turbine exhaust, Btu/lb
h_{REF}	Enthalpy of gas turbine exhaust at reference (compressor inlet) temperature, Btu/lb

ISO Firing Temperature

The ISO firing temperature (reference turbine inlet temperature) is not actually realized at any point in the turbine but represents the inlet temperature that would be obtained if the combustion inlet mass flow equaled the compressor inlet mass flow, i.e., no air extracted for turbine cooling. A substantial fraction of the compressor flow may be extracted for cooling. The ISO firing temperature is calculated by a mass and energy balance around the turbine combustion chamber per ISO Standard 2014 to obtain the gas enthalpy at the turbine inlet, as shown below. The gas temperature is obtained from this enthalpy. Changes in ISO firing temperature are useful in diagnosing gas turbine performance problems.

$$h_{TI} = \frac{\dot{m}_A \left(h_{CD} - h_{AREF} \right) + Q_{FHI}}{\dot{m}_{EXH}} + h_{EREF}$$ **Equation 13-6**

where

h_{TI}	Enthalpy of gas turbine inlet, Btu/lb
$\dot{m}_A$	Air mass flow ($\dot{m}_{EXH} - \dot{m}_{FUEL}$), lb/h
h_{CD}	Enthalpy of air at compressor discharge, Btu/lb
h_{AREF}	Enthalpy of air at reference (compressor inlet) temperature, Btu/lb
Q_{FHI}	Fuel input, consisting of the chemical energy of the fuel plus sensible heat about reference, Btu/h
Q_{SI}	Heat input from steam injection, Btu/h
Q_{KW}	Gas turbine output, Btu/h
Q_{GL}	Generator loss, Btu/lb *(this may be from a manufacturer's curve or estimated)*
Q_{MISC}	Heat input from steam injection, Btu/h
$\dot{m}_{EXH}$	Exhaust mass flow, lb/h

Compressor Efficiency

The *GPCALCS Gas Turbine Performance Workbook* calculates isentropic (adiabatic) and polytropic compressor efficiencies. Trends of compressor efficiency are useful for determining the optimum schedule for compressor washes. Refer to **Chapter 6**, *Compressor Performance Workbook*, for information describing the compressor efficiency calculations.

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Heat Recovery Steam Generator (HRSG)

Performance Workbook

Heat Recovery Steam Generator (HRSG) Performance Workbook

This workbook calculates HRSG efficiency using the ASME Thermal-Loss Method, along with HRSG effectiveness and steaming capacity. Depending on the available instrumentation, performance of individual sections, as well as overall performance, is calculated. Exhaust gas flow is determined using one of four different methods. Three options are given for entering the exhaust gas composition used to determine gas enthalpy. Radiation loss used in the Loss Method is calculated using one of three different methods.

Computations are performed in general accordance with the ASME Performance Test code PTC 4.4, *Gas Turbine Heat Recovery Steam Generators*. The workbook can accommodate HRSGs with up to three pressure levels plus a reheater, with or without auxiliary duct firing. Important performance parameters are automatically displayed and printed in a concise report that compares test and design.

Measuring HRSG Performance

HRSG efficiency is defined as the ratio of heat absorbed by the steam and water circuits to the heat added to the boiler envelope. The principal source of heat input to the HRSG is the sensible heat in the gas turbine exhaust and chemical energy in the supplementary fuel (if used). Other sources of heat are ignored.

The output of the HRSG consists of the energy added to the steam and water circuits within the HRSG envelope. It is calculated by the measurement of all temperatures, pressures, and flows needed to compute the energy content of each working fluid stream as it enters and leaves the HRSG boundary. The number of streams will increase with multi-pressure HRSGs.

The ASME Thermal-Loss Method determines the major heat losses in the HRSG as a percentage of total heat input. The losses are subtracted from 100% to determine efficiency. Heat input and individual heat losses are computed relative to a reference temperature. This reference temperature is generally taken as the temperature of the air entering the gas turbine compressor. Enthalpy of the exhaust gas is calculated using the JANAF polynomial formulation as presented in the new boiler test code, PTC 4, *Fired Steam Generators*. This method requires an exhaust gas analysis.

Another means of determining the gas turbine exhaust sensible heat input to the HRSG is to perform an energy balance around the gas turbine. The electrical energy output of the gas turbine is subtracted from the heat input from fuel, air, and steam to arrive at exhaust energy. Adjustments must also be made for generator losses and losses in the gas turbine bearings. This approach may also be used to check on actual exhaust flow measurements.

The advantages of the Loss Method include decreased uncertainty levels and improved repeatability. In addition, this method requires fewer measurements than the Input/Output Method. Specifically, the Loss Method requires accurate measurement of HRSG exhaust gas inlet temperature, stack temperature, supplementary fuel flow rate, exhaust gas flow, and exhaust gas composition. Depending on the method selected for determination of the surface radiation and convection losses, some additional temperature measurements may be necessary.

Note *In an unfired HRSG without a bypass stack, the stack gas flow is equal to the HRSG inlet gas flow and cancels out when calculating the stack loss. When testing a HRSG with this arrangement, measurement of the exhaust gas flow will be unnecessary.*

The following major HRSG heat losses are determined by this procedure.

- **Heat Loss in Moist Exhaust Gas** leaving the HRSG up the stack to the atmosphere. This loss accounts for virtually all of the energy loss from the HRSG. Sensible heat in the flue gas leaving the HRSG is a function of exit gas temperature and the total flue gas flow.
- **Radiation and Convection Heat Loss** through the HRSG casing to ambient surroundings typically accounts for around 0.5% of the total heat input at full load. Because most HRSG installations are outdoors, this

loss will vary as ambient temperature and wind velocity vary. However, since it is such a small fraction of the total heat loss, assuming a constant loss will not impact accuracy significantly.

These parameters are measured for the Loss Method.

- **Flue Gas Analysis** gives the percentage by volume of the oxygen, nitrogen, carbon dioxide, and water vapor in the flue gas. It is used in the calculation of the flue gas enthalpy. Since small changes in flue gas composition have only a minor effect on enthalpy differences, it is sufficiently accurate to calculate flue gas composition based on fuel composition and estimated airflow to the gas turbine. Water vapor has a significant effect on the heat capacity of the flue gas, so it is important that water vapor from steam injection or other sources be included in the calculations.
- **Flue Gas Exit Gas Temperature** is measured at the HRSG stack.
- **Gas Temperature Entering the HRSG** is measured at the inlet to the HRSG at enough points to ensure that a true average temperature is obtained.
- **Reference Temperature** is measured at the gas turbine compressor inlet.

HRSG effectiveness is the ratio in percentage of the actual measured enthalpy drop of the HRSG gas across the section being evaluated relative to the maximum theoretically possible (MTP) enthalpy drop of the gas. The measured enthalpy drop of the HRSG gas is the difference between the enthalpies of HRSG gas at temperatures measured at the points entering and leaving the section being evaluated. The MTP enthalpy drop of the HRSG gas is the difference between the enthalpy of the gas entering and leaving the section being evaluated as would occur if the section had infinite heat transfer surface with the result that the HRSG gas temperature would equal the water/steam temperature(s) at one or more points in the section.

HRSG steaming capacity is subject to the energy available from the gas turbine. This test is simple to carry out and requires knowing the gas turbine exhaust flow and temperature entering the HRSG, and the steam flows, pressures, and temperatures leaving the HRSG. Maximum steaming capacity is reached when actual steam pressures and temperatures begin to fall below their rated values.

What You'll Need

Analyzing HRSG performance requires an exhaust gas analysis, and HRSG and gas turbine heat balances for the design data. Field measurements of operating conditions for both the HRSG and the gas turbine are required. It may also be necessary to provide a gas turbine and duct burner fuel analysis.

Design Data

The following design data is required:

- Ambient Temperature (Reference)
- Gas Side Gas Turbine Exhaust Temperature
- HRSG Gas Flow
- Gas Side Stack Temperature
- Exhaust Gas Analysis
- Auxiliary Duct firing Fuel heat Input
- Atomizing Steam Flow
- Augmenting Air Flow
- HP Superheater Outlet Temperature and Pressure
- HP Steam Flow
- HP Drum Pressure
- HP Economizer Inlet Temperature and Pressure
- HP Feedwater Flow to Economizer
- Reheater Outlet Temperature and Pressure
- Reheater Steam Flow
- Reheater Inlet Temperature and Pressure
- IP Superheater Outlet Temperature and Pressure
- IP Steam Flow
- IP Drum Pressure
- IP Economizer Inlet Temperature and Pressure
- IP Feedwater Flow to Economizer
- LP Superheater Outlet Temperature and Pressure
- LP Steam Flow
- LP Drum Pressure
- LP Economizer/Condenser Preheater Inlet Temperature and Pressure
- LP Economizer/Condenser Preheater Inlet Flow

Test Data

Test data necessary for calculating HRSG performance include:

- Ambient Air Dry Bulb Temperature
- Ambient Air Wet Bulb Temperature
- Ambient Air Relative Humidity

- Barometric Pressure
- Wind Velocity
- HRSG Operating Conditions
- HRSG Section Operating Conditions (HP Superheater/Evaporator/Economizer)
- Gas Turbine Operating Conditions
- Exhaust Gas Composition
- Gas Turbine and Duct Burner Fuel Analysis

You must choose whether to use the wet bulb temperature of the relative humidity in calculations.

You must specify the method used to determine the exhaust gas flow. There are four Exhaust Gas Flow Methods:

- **Method 1:** Ignore exhaust flow assuming no duct firing and no leakage so that stack flow equals entering flow. Radiation loss is ignored or entered manually.
- **Method 2:** Manually enter the exhaust flow.
- **Method 3:** Calculate the exhaust flow using the gas turbine heat balance from gas turbine operating conditions and fuel properties.
- **Method 4:** Calculate the exhaust flow using the HRSG section energy balance from HRSG operating conditions.

You must choose one of the three Exhaust Gas Analysis Options:

- **Option 1:** Use the design exhaust gas analysis.
- **Option 2:** Manually input the exhaust gas analysis.
- **Option 3:** Calculate the exhaust gas analysis based on the gas turbine and auxiliary gas firing operating conditions.

You must also choose one of the three Radiation/Convection Loss Method Options:

- **Option 1:** Manually input the radiation loss.
- **Option 2:** Use the ABMA Loss Curve.
- **Option 3:** Use the PTC 4.4, *Surface and Ambient Air Temperature-Velocity Method*, based on the HRSG exposed surface area, HRSG average skin temperature, and surface emissivity.

Workbook Calculations

As noted previously, the *GPCALCS HRSG Performance Workbook* calculates the efficiency, effectiveness, and steaming capacity of the HRSG. These are described below.

Efficiency

Overall HRSG efficiency by the Thermal-Loss Method is calculated, as follows:

$$\eta_{HRSG} = 100\left(1 - \frac{Q_{ST}}{Q_{INPUT}}\right) - R$$ **Equation 14-1**

where

η_{HRSG}	Overall HRSG efficiency, %
Q_{ST}	Heat in flue gas leaving HRSG, % (see **Equation 14-2**
Q_{INPUT}	Sensible heat input to the HRSG, Btu/h (see **Equation 14-3**)
R	Radiation loss, %

The largest component of the HRSG energy loss is the stack energy loss, Q_{ST}. Stack energy loss is determined based on the difference in enthalpy of the stack gas at its measured temperature and the enthalpy of the stack gas at ambient or reference temperature.

$$Q_{ST} = \dot{m}_{HRSG}(h_{ST} - h_{REF})$$ **Equation 14-2**

where

$\dot{m}_{HRSG}$	Stack gas flow, lb/h
h_{ST}	Enthalpy of stack gas at stack temperature, Btu/lb
h_{REF}	Enthalpy of stack gas at reference temperature, Btu/lb *(assumed to ambient temperature)*

The sensible heat input to the HRSG, Q_{INPUT}, is calculated, as follows:

$$Q_{INPUT} = Q_{FUEL} - Q_{KW} - Q_{MISC}$$ **Equation 14-3**

where

Q_{FUEL}	Heat input from combustion turbine fuel, Btu/h
Q_{KW}	Combustion turbine power output, Btu/h
Q_{MISC}	Miscellaneous heat losses, Btu/h

The heat input from combustion turbine fuel, Q_{FUEL}, is calculated, as follows:

$$Q_{FUEL} = W_{FUEL}(LHV)$$ **Equation 14-4**

where

W_{FUEL}	Combustion fuel consumption, lb/h
LHV	Combustion turbine fuel lower heating value, Btu/lb

The heat equivalent of the average hourly combustion turbine power output, Q_{KW}, is calculated, as follows:

$$Q_{KW} = 3412.14(GT_{KW_{TEST}})$$ **Equation 14-5**

where

Q_{KW}	Combustion turbine power output, Btu/h

GT_{KWTEST}	Average combustion turbine power output, kW
3412.12	Conversion factor, Btu/h/kW

Miscellaneous losses, Q_{MISC}, include shaft-driven auxiliary equipment, heat given up to the gas turbine lubricating oil and cooling systems, and generator losses. The effect of these losses in the calculation of overall efficiency, using the Thermal-Loss Method, is generally small in magnitude. Therefore, an estimate from the combustion turbine generator manufacturer's data is used as a percentage of fuel heat input.

Radiation/convection loss can be measured directly, estimated from the ABMA Loss Curve in ASME PTC 4, or calculated from the ASME PTC 4.4, *Ambient Air Temperature-Velocity Method*.

Overall Effectiveness

Overall effectiveness is calculated as the ratio of the actual gas enthalpy drop to the enthalpy drop that would result from cooling the gas to the temperature of the incoming condensate. Overall HRSG efficiency by the Input-Output Method is calculated as follows:

$$E = \frac{\text{Actual enthalpy change of the exhaust gas}}{\text{MTP enthalpy change of the exhaust gas}} \times 100 = \frac{h_2 - h_1}{h_2 - h_i} \times 100 \qquad \textbf{Equation 14-6}$$

where

E	overall effectiveness, %
h_2	Enthalpy of exhaust gas at inlet temperature, Btu/lb
h_1	Enthalpy of exhaust gas at outlet temperature, Btu/lb
h_i	Enthalpy of exhaust gas at inlet water temperature, Btu/lb
MTP	Maximum theoretically possible

Section Effectiveness

Section effectiveness is calculated as the ratio of the actual gas enthalpy drop to the maximum theoretically possible drop, accounting for both the temperature of the incoming fluid and the evaporator pinch. Another way to think of effectiveness is that a heat transfer section would be 100% effective if it were infinitely large enough to result in the HRSG gas temperature leaving the section equaling the water/steam temperature entering the section. The effectiveness of an economizer is expressed, as follows:

$$E = \frac{(h_{G1} - h_{G4})(h_{s1} - h_{w2})}{(h_{G1} - h_{Gs3})(h_{s1} - h_{w4})} \times 100 \qquad \textbf{Equation 14-7}$$

where

E	overall effectiveness, %
h_{G1}	Enthalpy of HRSG gas at inlet temperature, Btu/lb
h_{G4}	Enthalpy of HRSG gas at outlet temperature, Btu/lb
h_{s1}	Enthalpy of superheated steam at outlet temperature, Btu/lb

h_{w2} Enthalpy of water at saturated steam temperature, Btu/lb
h_{Gs3} Enthalpy of HRSG gas at a temperature equal to the saturated steam temperature in the boiler drum, Btu/lb
h_{w4} Enthalpy of water at inlet temperature, Btu/lb

Capacity

Capacity is defined as either actual evaporation in terms of mass flow of steam per unit time or heat absorbed by the working fluids per unit of time. HRSG steaming capacity is subject to the energy available from the gas turbine. This test is simple to carry out and requires knowing the gas turbine exhaust flow and temperature entering the HRSG and the steam flows, pressures, and temperatures leaving the HRSG. Maximum steaming capacity is reached when actual steam pressures and temperatures begin to fall below their rated values.

15

Pump Performance Workbook

Pump Performance Workbook

This workbook calculates total developed head (static+velocity+gravity), net positive suction head (NPSH), and efficiency. Calculated test values are compared to design values based on flow and rated speed, corrected to pump speed and inlet temperature. Computations are performed using techniques given in ASME Performance Test Code PTC 8.2, *Centrifugal Pumps*. These performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Measuring Pump Performance

Boiler feed pumps are important pieces of auxiliary equipment whose condition plays a major role in the heat rate and maximum capacity of a generating unit. Calculating total developed head (static+velocity+gravity), net positive suction head (NPSH), and efficiency requires accurate measurement of suction pressure and temperature, discharge pressure and temperature, and pump flow. Each of these performance indices can be trended over time to detect changes in pump condition.

What You'll Need

Analyzing pump performance requires few field measurements.

Design Data

The following pump design data is required:

- Rated Speed
- Rated Flow
- Total Developed Head at Rated Flow
- NPSH at Rated Flow
- Pump Efficiency
- Graph of Design Flow Capacity, Total Developed Head, Pump Efficiency, and Shaft Power (*optional*)

Test pump head and capacity are corrected to design pump speed.

The following motor design data is required:

- Power
- Voltage
- Rated Speed
- Motor Efficiency
- Motor Power Factor

Test Data

Test data necessary for calculating pump performance include:

- Pump Suction Pressure
- Pump Suction Temperature
- Pump Discharge Pressure
- Pump Discharge Temperature
- Pump Flow
- Suction Pipe ID
- Discharge Pipe ID
- Suction Water Leg
- Discharge Water Leg

For pumps powered by electric motors, power output is easily determined from watt-hour meters or watt transducers. For gas turbines used to drive compressors and pumps, power output is not normally available. In these cases, power output can be estimated from calculations made on the driven component. Refer to the appropriate GPCALCS workbook for methods for determining drive power requirements.

Workbook Calculations

When considering pump performance, test results must be corrected to a standard condition for comparison. The Affinity Laws state that test flow, head, and water horsepower can be extrapolated from test speed values to design speed values by multiplying each parameter by a correction factor.

For flow, the correction factor is the ratio of design speed (5,600 rpm) to test speed (see **Equation 15-1**). For total head, the corrections factor is the ratio squared (see **Equation 15-2**). For water horsepower, it is the ratio cubed (see **Equation 15-3**). To use these relationships, an accurate measurement of pump speed must be made during the test.

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2}$$ **Equation 15-1**

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2$$ **Equation 15-2**

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$ **Equation 15-3**

where

$n_{1,2}$	Pump speed, rpm
$Q_{1,2}$	Pump capacity, gpm
$H_{1,2}$	Pump head, ft
$P_{1,2}$	Pump power input, bhp

Pump Suction Head

Pump suction head is calculated as shown below.

$$H_s = H_{sp} + H_{sv} + WL_s$$ **Equation 15-4**

where

H_s	Total suction head, ft
H_{sp}	Total suction pressure head, ft (see **Equation 15-5**)
H_{sv}	Total suction velocity head, ft (see **Equation 15-6**)
WL_s	Suction water leg, ft

The total suction pressure head is calculated as shown below.

$$H_{sp} = \frac{144P_s}{\rho}$$ **Equation 15-5**

where

H_{sp}	Total suction pressure head, ft
P_s	Suction pressure, psia
ρ	Suction fluid density, lbm/ft^3

The total suction velocity head is calculated as shown below.

$$H_{sv} = \frac{V^2}{2g}$$ **Equation 15-6**

where

H_{sv}	Total suction velocity head, ft
V	Suction velocity, fps
g	Acceleration of gravity (32.2 ft/s^2)

Pump Discharge Head

Pump discharge head is calculated as shown below.

$$H_d = \frac{144P_d}{\rho} + \frac{V^2}{2g} + WL_d$$ **Equation 15-7**

where

H_d Total discharge head, ft
P_d Discharge pressure, psia
ρ Discharge fluid density, lbm/ft^3
V Discharge Velocity, fps
g Acceleration of gravity (32.2 ft/s^2)
WL_d Discharge water leg, ft

Total Developed Head

Total developed head is the total discharge head minus the total suction head.

$$H_T = H_d - H_s$$ **Equation 15-8**

where

H_T Total developed head, ft
H_d Total discharge head, ft (see **Equation 15-7**)
H_s Total suction head, ft (see **Equation 15-4**)

Net Positive Suction Head

The net positive suction head is calculated as shown below.

$$NPSH = h_s - \frac{144VP_s}{\rho}$$ **Equation 15-9**

where

NPSH Total net positive suction head, ft
VP_s Suction vapor pressure, psia
ρ Suction fluid density, lbm/ft^3

Pump Efficiency

Pump efficiency is determined on the basis that brake horsepower is constant between the two curves at any given head value. The degree of deficiency is the inability of the pump to deliver rated flow. This approach is presented below mathematically:

$$\eta_p = \frac{whp_f}{bhp_f} \times 100$$ **Equation 15-10**

where

η_p Pump efficiency, %
whp_f Measured useful pump power output, hp
bhpf Measured drive motor power output, hp

16

Utility Steam Turbine Performance Workbook

Utility Steam Turbine Performance Workbook

This workbook calculates the utility steam turbine performance indices of HP and IP turbine section enthalpy-drop efficiencies. Calculations include the determination of HP to IP steam leakage flow rate for common casing turbines using both the Temperature Variation and Constant Slope Methods. IP section efficiency is calculated and reported with and without the leakage flow.

Calculated test values are compared to design values and the effects of any deviations on turbine cycle heat rate and generator capacity are calculated. Computations are performed using the techniques found in ASME PTC 6S Report, *Procedures for Routine Performance Tests of Steam Turbines* and K. C. Cotton's *Evaluating and Improving Steam Turbine Performance.* Important performance parameters are automatically displayed and printed in a concise report that compares test, design, and corrected values.

Measuring Utility Steam Turbine Performance

Utility team turbine generator performance is affected by conditions both internal and external to the turbine casing. Internal conditions that decrease performance include wear and damage to buckets, diaphragms, and seals. A combination of enthalpy-drop efficiency tests and observation of changes in corrected stage pressures can often detect these conditions. The effect of these deviations should always be correlated to changes in corrected generator capability through a kilowatt check.

External conditions that decrease performance include feedwater heater performance, air preheating requirements, auxiliary steam supply requirements, condenser performance, and heater drain disposition. For test purposes, most external conditions can be eliminated either by appropriate isolation practices or by correction factors applied during engineering calculations.

What You'll Need

Assessing turbine section enthalpy-drop efficiency requires a turbine cycle heat balance to provide design and test data of temperature and pressure.

Design Data

The following turbine design data are required and are generally available on a valves-wide-open (VWO) heat balance:

- Throttle Flow, Pressure, and Temperature
- First Stage Enthalpy Drop at VWO
- HP to IP Leakage Flow
- Cold Reheat Pressure and Temperature
- Hot Reheat Pressure and Temperature
- IP Exhaust Pressure and Temperature
- Design Pressure Drops at the IP Exhaust (*see workbook for guidance*)
- Gross Generation at VWO
- HP Turbine Generation at VWO
- IP Turbine Generation at VWO

Test Data

Test data necessary for calculating steam turbine enthalpy–drop efficiencies include:

- Throttle Pressure and Temperature
- First Stage Pressure
- Cold Reheat Pressure and Temperature
- Hot Reheat Pressure and Temperature
- Crossover Pressure and Temperature
- Barometric Pressure (if pressure transmitters read gauge pressure)

Workbook Calculations

The Steam Turbine Performance Workbook calculates HP and IP section enthalpy-drop efficiencies, actual and design. Deviations from design and their effect on turbine cycle heat rate and generator capacity are calculated. These are described below.

HP Section Enthalpy-Drop Efficiency

The enthalpy-drop efficiency test measures how much of the available energy in the steam supplied to the turbine is used to produce power. It is defined as follows:

$$\eta_{hp} = \frac{h_{thr} - h_{crh}}{h_{thr} - h_{crhi}} x100\%$$ **Equation 16-1**

where

η_{hp} HP enthalpy-efficiency, %

h_{thr} Steam enthalpy at throttle pressure and temperature, Btu/lb

h_{crh} Steam enthalpy at cold reheat pressure and temperature, Btu/lb

h_{crhi} Steam enthalpy at cold reheat pressure and throttle entropy, Btu/lb

IP Section Enthalpy-Drop Efficiency

IP steam turbine enthalpy-drop efficiency from hot reheat to LP bowl conditions is calculated, as shown below.

$$\eta_{ip} = \frac{h_{hrh} - h_{lpb}}{h_{hrh} - h_{lpbi}} x100\%$$ **Equation 16-2**

where

η_{ip} IP enthalpy-efficiency, %

h_{hrh} Steam enthalpy at hot reheat pressure and temperature, Btu/lb

h_{lpb} Steam enthalpy at LP bowl pressure and temperature, Btu/lb

h_{lpbi} Steam enthalpy at LP bowl pressure and hot reheat entropy, Btu/lb

Calculation of efficiency using **Equation 16-2** does not consider the effect of N2 leakage and is not a sufficient indication of IP steam turbine section condition. The following methods can be used to determine a more accurate indication of IP efficiency.

- **Estimating the Effect of N2 Leakage on Calculated IP Efficiency—** Leakage of steam from the HP to the IP bowl along the N2 packing effects only the calculated IP efficiency. It has no real effect on actual IP efficiency. The N2 leakage entering the IP bowl lowers the enthalpy of the steam entering the IP stages. The cooling effect of the N2 leakage is considered by calculating a “mixed” enthalpy. A mass and energy balance on the IP bowl yields the following relationship for IP bowl enthalpy.

$$h_{ipbowl} = \frac{h_{hrh} + \frac{\%N2}{100} h_{N2}}{1 + \frac{\%N2}{100}}$$ **Equation 16-3**

where

h_{ipbowl}	IP bowl steam enthalpy, Btu/lb
h_{hrh}	Steam enthalpy at hot reheat pressure and temperature, Btu/lb
%N2	N2 leakage flow, % of reheat flow
h_{N2}	N2 leakage steam enthalpy, Btu/lb

Equation 16-3 expresses N2 leakage flow as a percentage of reheat flow. It is also sometimes expressed as a percentage of IP bowl flow (reheat flow plus N2 leakage). Either approach is acceptable, provided the calculated bowl enthalpy is based on proper mass and energy balances performed on the IP bowl. To convert from one form to the other, use **Equation 16-4**.

$$\%N2_{ipbowl} = \frac{\%N2_{reheat}}{1 + \frac{\%N2_{reheat}}{100}}$$ **Equation 16-4**

The base N2 leakage steam enthalpy can be estimated from the heat balance closest to the test throttle flow. The difference between the actual and design throttle enthalpy should be added to the base N2 leakage to determine the N2 enthalpy, h_{N2}, used in **Equation 16-3**. Another method to estimate N2 enthalpy directly is to draw the HP steam turbine expansion line on the Mollier Diagram and read the enthalpy at the first stage pressure. Either method is acceptable since the test results are insensitive to the magnitude of the N2 leakage enthalpy.

The IP bowl entropy is determined at IP bowl pressure (hot reheat pressure less than 2%) and enthalpy. The IP efficiency is then calculated, as follows:

$$\eta_{ipN2} = \frac{h_{ipbowl} - h_{lpb}}{h_{ipbowl} - h_{lpbi}} x100$$ **Equation 16-5**

where

η_{ipN2}	IP enthalpy-efficiency, including N2 leakage, %
h_{hibowl}	Steam enthalpy at IP bowl, Btu/lb
h_{lpb}	Steam enthalpy at LP bowl pressure and temperature, Btu/lb
h_{lpbi}	Steam enthalpy at LP bowl pressure (+3%) and IP bowl entropy, Btu/lb

Note

The ideal exhaust enthalpy is determined at the IP bowl entropy and the LP bowl pressure plus a 3% pressure loss that occurs from the IP exhaust to the LP bowl. This adjustment is necessary for comparing measured performance to expected performance determined from procedures found in K. C. Cotton's Evaluating and Improving Steam Turbine Performance*.*

- **Temperature Variation Method for Estimating N2 Leakage and IP Efficiency**—The Temperature Variation Method requires at least two efficiency tests with throttle and reheat temperatures mismatched. From each test's raw data, two efficiencies are calculated, one using **Equation 16-2** (no leakage) and another using **Equations 16-3** and **16-5**. For the efficiency computed using **Equations 16-3** and **16-5**, an arbitrary value for N2 leakage flow (percentage N2) of 10% is assumed. The resulting efficiencies are plotted versus percentage N2. The efficiency and percentage N2 leakage corresponding to the intersection of the two lines are the test efficiency and test leakage that should be compared to design.
- **Slope Method for Estimating N2 Leakage and IP Efficiency**—The Slope Method for estimating N2 requires at least two efficiency tests, one at full load and one at a lower load. From each test's raw data, two efficiencies are calculated using **Equation 16-2** (no leakage) and plotted versus throttle flow ratio. This line is labeled uncorrected. From the same data, two efficiencies are computed using **Equations 16-3** and **16-5** and an assumed percentage N2 leakage of 5%. Plot the result on the same graph as the uncorrected results. If the graph has a positive slope, reduce the assumed leakage and recompute the efficiencies. For negative slopes, increase the assumed leakage and recompute the efficiencies. Repeat this process until the two efficiencies equal one another. The resulting efficiency and percentage N2 leakage are the test efficiency and test leakage that should be compared to design.

17

GPCALCS Library

GPCALCS Library

GPCALCS Library functions allow you to calculate the thermodynamic properties of air and steam, supplied as part of the GPCALCS Excel Add-in. In addition, a tool is provided for psychrometric functions.

Accurate thermodynamic properties of water and steam are function calls available for all your Excel spreadsheet applications. Properties are in accordance with ASME IFC67 and IFC97 formulations.

To verify that the steam tables are now available in Excel, type **"=GPXPTH(2400,1000)"** into any cell and then press the **Enter** key. An enthalpy of 1460.89 Btu/lbm returns for steam at 2400 psia and 1000°F using the IFC-67 Formulation or an enthalpy of 1461.1 Btu/lbm for the IFC97 Formulation.

Thermodynamic properties can be determined for all points defined by the pressures between the triple point and 15,000 psia (221.20 bar), and temperatures between the triple points and 1600°F (871°C). In a saturated region, all properties are defined for values of quality between 0% and 100%.

The following list gives the specific operational ranges for the state points.

- Pressure: 0.0887-15,000 psia (0.006-221.20. bar)
- Temperature: 25.002-1600°F (-3.9-871°C)
- Enthalpy: 0-1860 Btu/lbm (0-4326.4 kJ/kg)
- Entropy: 0-3.0 Btu/lbm °R (0-12.560 kJ/kg K)
- Quality: 0-1

Note

The ranges given are for general information. There may be various combinations of parameters that will not return a valid result, such as certain calls in the wet region and near the critical point.

In addition, GPCALCS Excel Add-in functions are provided to return the thermodynamic properties of moist air at or near atmospheric pressure. Little error will be introduced at pressures typical of gas turbine cycles.

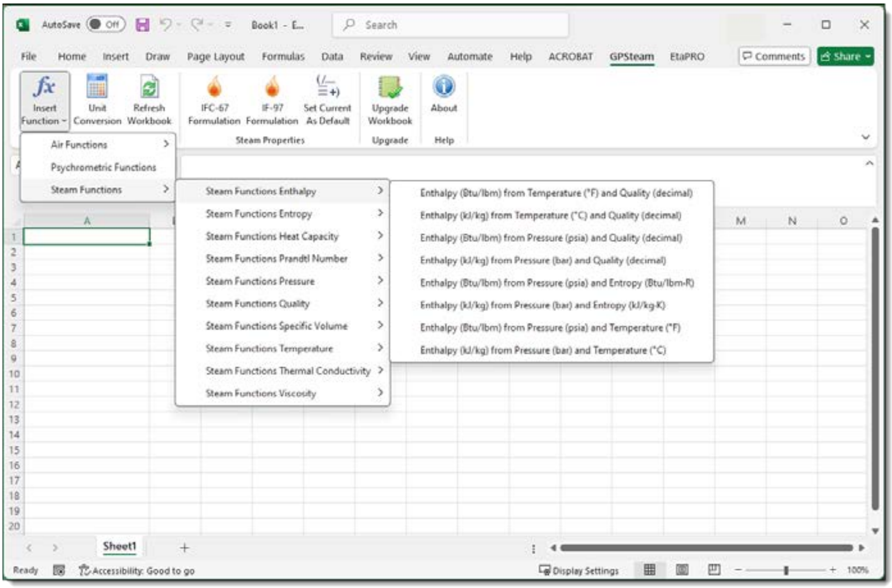
- If the optional specific humidity is omitted, the properties of dry air are returned.
- The reference temperature for enthalpy is 77°F (25°C).

Using GPCALCS Library Functions in Excel

Insert Air and Steam Functions

1. Open Excel and highlight the output cell on your worksheet.
2. Select the **GPCALCS|Insert Function|Steam (or Air) Functions** command to display the list of thermodynamic properties and the list of functions for each (refer to **Figure 17-1**).

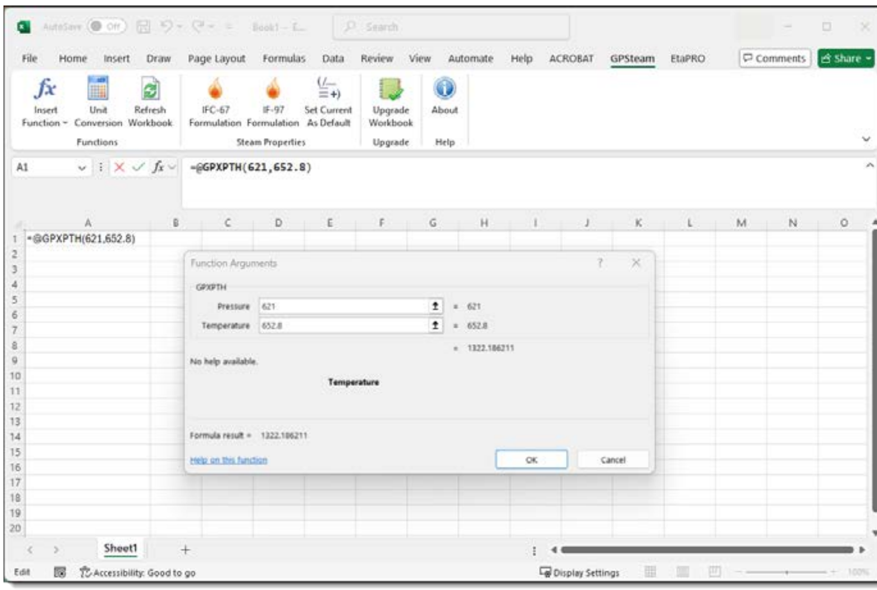
Figure 17-1 Steam Functions in Excel



3. Highlight the function and then click on it to display its *Function Arguments* dialog.

4. Enter a value for the first argument or use a cell reference as an argument by clicking on the icon in the **property** field to display the *Function Arguments* dialog. Click in the cell on the worksheet with that property value. Use the **F4** key scroll to through all the various combinations of absolute and relative references to lock in the column and/or row number with the $ sign.
5. Click on the icon to return to the selected *Function Arguments* dialog.
6. Repeat **Step 4** to enter the value of the second argument (refer to **Figure 17-2**).

Figure 17-2 Function Argument Dialog

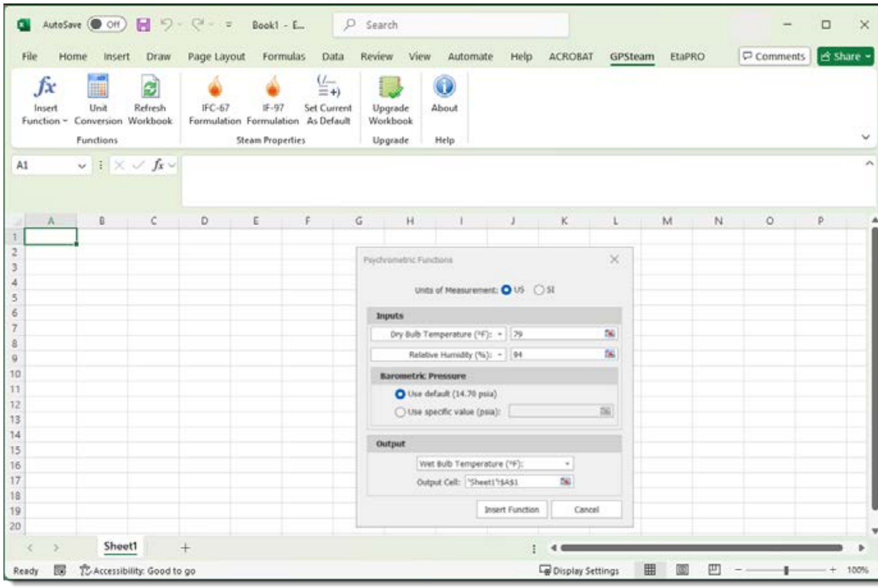


7. Click **OK** to close the *Functions Arguments* dialog and display the result on the worksheet.

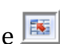
Insert Psychrometric Functions

1. Open Excel and highlight the output cell on your worksheet.
2. Select the **GPCALCS|Insert Function|Psychrometric Functions** command.
3. The *Psychrometric Functions* dialog displays (refer to **Figure 17-3**).

Figure 17-3 Psychrometric Functions Dialog



4. Enter the input values for either dry bulb or wet bulb temperature and relative humidity, wet bulb temperature, or specific humidity, as appropriate.

5. You can cell references as arguments for these input values by clicking on the  icon in the **property** field to display the *Function* Arguments dialog. Click in the cell on the worksheet with that property value. Use the **F4** key scroll to through all the various combinations of absolute and relative references to lock in the column and/or row number with the $ sign.

6. Click on the  icon to return to the selected *Function Arguments* dialog.

7. Select either a default barometric pressure or enter a specific value or a cell reference.

8. Select either a result of wet bulb temperature or specific humidity and its output cell.

9. Click **OK** to close the *Functions Arguments* dialog and display the result on the worksheet.

Excel Library Functions for Air and Steam

The following function calls are used to obtain air or steam values in Excel. Argument values are entered directly or referenced by cell addresses. Both English and metric units can be used. The “Me” designation in the statement returns the metric units.

AIR FUNCTIONS

Enthalpy (H)

=AIRXTSH(T,S)
Returns Enthalpy, Btu/lbm from Temperature, °F and Specific Humidity

=AIRXTSHME(T,S)
Returns Enthalpy, kJ/kg from Temperature, °C and Specific Humidity

Heat Capacity (Cp)

=AIRXTSCp(T,S)
Returns Heat Capacity (Cp), Btu/lb·°R from Temperature, °F and Specific Humidity

=AIRXTSCpMe(T,S)
Returns Heat Capacity (Cp), kJ/kg·°K from Temperature, °C and Specific Humidity

=AIRXTSK(T,S)
Returns Heat Capacity Ratio (Cp/Cv) from Temperature, °F and Specific Humidity

=AIRXTSKMe(T,S)
Returns Heat Capacity Ratio (Cp/Cv) from Temperature, °C and Specific Humidity

Temperature (T)

=AIRXHST(H,S)
Returns Temperature, °F from Enthalpy, Btu/lbm and Specific Humidity

=AIRXHSTMe(H,S)
Returns Temperature, °C from Enthalpy, kJ/kg and Specific Humidity

STEAM FUNCTIONS

Enthalpy (H)

=GPXPQH(P,Q)
Returns Enthalpy, Btu/lbm from Pressure, psia and Quality, decimal

=GPXPQHMe(P,Q)
Returns Enthalpy, kJ/kg from Pressure, bar and Quality, decimal

=GPXPSH(P,S)
Returns Enthalpy, Btu/lbm from Pressure, psia and Entropy, Btu/lbm·°R

=GPXPSHMe(P,S)
Returns Enthalpy, kJ/kg from Pressure, bar and Entropy, kJ/kg·°K

=GPXPTH(P,T)
Returns Enthalpy, Btu/lbm from Pressure, psia and Temperature, °F

=GPXPTHMe(P,T)
Returns Enthalpy, kJ/kg from Pressure, bar and Temperature, °C

=GPXTQH(T,Q)
Returns Enthalpy, Btu/lbm from Temperature, °F and Quality, decimal

=GPXTQHMe(T,Q)
Returns Enthalpy, kJ/kg from Temperature, °C and Quality, decimal

Entropy (S)

=GPXPHS(P,H)
Returns Entropy, Btu/lbm·°R from Pressure, psia and Enthalpy, Btu/lbm

=GPXPHSMe(P,H)
Returns Entropy, kJ/kg·°K from Pressure, bar and Enthalpy, kJ/kg

=GPXPQS(P,Q)
Returns Entropy, Btu/lbm·°R from Pressure, psia and Quality, decimal

=GPXPQSMe(P,Q)
Returns Entropy, kJ/kg·°K from Pressure, bar and Quality, decimal

=GPXPTS(P,T)
Returns Entropy, Btu/lbm·°R from Pressure, psia and Temperature, °F

=GPXPTSMe(P,T)
Returns Entropy, kJ/kg·°K from Pressure, bar and Temperature, °C

=GPXTQS(T,Q)
Returns Entropy, Btu/lbm·°R from Temperature, °F and Quality, decimal

=GPXTQSMe(T,Q)
Returns Entropy, kJ/kg·°K from Temperature, °C and Quality, decimal

Heat Capacity (C)

=GPXPQC(P,Q)
Returns Heat Capacity (Cp), Btu/lb·°F from Pressure, psia and Quality, decimal

=GPXPQCMe(P,Q)
Returns Heat Capacity (Cp), kJ/kg·°K from Pressure, bar and Quality, decimal

=GPXPTC(P,T)
Returns Heat Capacity (Cp), Btu/lb·°F from Pressure, psia and Temperature, °F

=GPXPTCMe(P,T)
Returns Heat CapacitY (Cp), kJ/kg·°K from Pressure, bar and Temperature, °C

=GPXTQC(T,Q)
Returns Heat Capacity (Cp), Btu/lb·°F from Temperature, °F and Quality, decimal

=GPXTQCMe(T,Q)
Returns Heat Capacity (Cp), kJ/kg·°K from Temperature, °C and Quality, decimal

Prandtl Number (L)

=GPXPQL(P,S)
Returns Prandtl Number, dimensionless from Pressure, psia and Quality, decimal

=GPXPQLMe(P,S)
Returns Prandtl Number, dimensionless from Pressure, bar and Quality, decimal

=GPXPTL(P,T)
Returns Prandtl Number, from Pressure, psia and Temperature, °F

=GPXPTLMe(P,T)
Returns Prandtl Number, from Pressure, bar and Temperature, °C

=GPXTQL(T,Q)
Returns Prandtl Number, from Temperature, °F and Quality, decimal

=GPXTQLMe(T,Q)
Returns Prandtl Number, from Temperature, °C and Quality, decimal

Pressure (P)

=GPXHSP(H,S)
Returns Pressure, psia from Enthalpy, Btu/lbm and Entropy, Btu/lbm·°R

=GPXHSPMe(H,S)
Returns Pressure, bar from Enthalpy, kJ/kg and Entropy, kJ/kg·°K

=GPXTP(T)
Returns Saturation Pressure, psia from Temperature, °F

=GPXTPMe(T)
Returns Saturation Pressure, bar from Temperature, °Cl

Quality (Q)

=GPXPHQ(P,H)
Returns Quality, decimal from Pressure, psia and Enthalpy, Btu/lbm

=GPXPHQMe(P,H)
Returns Quality, decimal from Pressure, bar and Enthalpy, kJ/kg

=GPXPSQ(P,S)
Returns Quality, decimal from Pressure, psia and Entropy, Btu/lbm·°R

=GPXPSQMe(P,S)
Returns Quality, decimal from Pressure, bar and Entropy, kJ/kg·°K

Specific Volume (V)

=GPXHSV(H,S)
Returns Specific Volume, ft3/lbm from Enthalpy, Btu/lbm and Entropy, Btu/lbm·°R

=GPXHSVMe(H,S)
Returns Specific Volume, m3/kg from Enthalpy, kJ/kg and Entropy, kJ/kg·°K

=GPXPHV(P,H)
Returns Specific Volume, ft3/lbm from Pressure, psia and Enthalpy, Btu/lbm

=GPXPHVMe(P,H)
Returns Specific Volume, m3/kg from Pressure, bar and Enthalpy, kJ/kg

=GPXPQV(P,Q)
Returns Specific Volume, ft3/lbm from Pressure, psia and Quality, decimal

=GPXPQVMe(P,Q)
Returns Specific Volume, m3/kg from Pressure, bar and Quality, decimal

=GPXPSV(P,S)
Returns Specific Volume, ft3/lbm from Pressure, psia and Entropy, Btu/lbm·°R

=GPXPSVMe(P,S)
Returns Specific Volume, m3/kg from Pressure, psia and Entropy, Btu/lbm·°R

=GPXPTV(P,T)
Returns Specific Volume, ft3/lbm from Pressure, psia and Temperature, °F

=GPXPTVMe(P,T)
Returns Specific Volume, m3/kg from Pressure, bar and Temperature, °C

=GPXTQV(T,Q)
Returns Specific Volume, ft3/lbm from Temperature, °F and Quality, decimal

=GPXTQVMe(T,Q)
Returns Specific Volume, m3/kg from Temperature, °C and Quality, decimal

Temperature (T)

=GPXHST(H,S)
Returns Temperature, °F from Enthalpy, Btu/lbm and Entropy, Btu/lbm·°R

=GPXHSTMe(H,S)
Returns Temperature, °C from Enthalpy, kJ/kg and Entropy, kJ/kg·°K

=GPXPHT(P,H)
Returns Temperature, °F from Pressure, bar and Enthalpy, kJ/kg

=GPXPHTMe(P,H)
Returns Temperature, °C from Pressure, bar and Enthalpy, kJ/kg

=GPXPST(P,S)
Returns Temperature, °F from Pressure, psia and Entropy, Btu/lbm·°R

=GPXPSTMe(P,S)
Returns Temperature, °C from Pressure, psia and Entropy, Btu/lbm·°R

=GPXPT(P)
Returns Saturation Temperature, psia from Pressure, psia

=GPXPTMe(P)
Returns Saturation Temperature, bar from Pressure, bar

Thermal Conductivity (K)

=GPXPQK(P,Q)
Returns Thermal Conductivity (Cp), Btu/hr-ft °F from Pressure, psia and Quality, decimal

=GPXPQKMe(P,Q)
Returns Thermal Conductivity (Cp), Watt/m·°K from Pressure, bar and Quality, decimal

=GPXPTK(P,T)
Returns Thermal Conductivity (Cp), Btu/hr-ft °F from Pressure, psia and Temperature, °F

=GPXPTKMe(P,T)
Returns Thermal Conductivity (Cp), kJ/kg·°K from Pressure, bar and Temperature, °C

=GPXTQK(T,Q)
Returns Thermal Conductivity (Cp), Btu/hr-ft °F from Temperature, °F and Quality, decimal

=GPXTQKMe(T,Q)
Returns Thermal Conductivity (Cp), Watt/m·°K from Temperature, °C and Quality, decimal

Viscosity (M)

=GPXPQM(P,Q)
Returns Viscosity, lbm/ft-hr from Pressure, psia and Quality, decimal

=GPXPQMMe(P,Q)
Returns Viscosity, Pa-sec from Pressure, bar and Quality, decimal

=GPXPTM(P,T)
Returns Viscosity, lbm/ft-hr from Pressure, psia and Temperature, °F

=GPXPTMMe(P,T)
Returns Viscosity, Pa-sec from Pressure, bar and Temperature, °C

=GPXTQM(T,Q)
Returns Viscosity, lbm/ft-hr from Temperature, °F and Quality, decimal

=GPXTQMMe(T,Q)
Returns Viscosity, Pa-sec from Temperature, °C and Quality, decimal

18

GPSteam Properties Calculator

GPSteam Properties Calculator

The thermodynamic properties of steam and water are provided by the GPCALCS Library, described in the previous chapter. The GPSteam Properties Calculator accesses the GPCALCS Library with pairs of user-entered values. The pair of values, which consist of various combinations of pressure, temperature, quality, enthalpy, or entropy, are entered to calculate the remaining thermodynamic properties for any given state point. These values are then updated in the calculator value fields, and the pressure in psia, temperature in °F, and percentage moisture content are plotted on a Mollier diagram for a visual indication of the fluid's enthalpy and entropy.

A state point is defined by selecting two thermodynamic properties for input. The steam property calculator accepts the following combinations:

- Pressure and Temperature
- Pressure and Quality
- Pressure and Enthalpy
- Pressure and Entropy
- Temperature and Quality
- Pressure and Quality
- Pressure and Efficiency *
- Enthalpy and Efficiency *
- Pressure and Used Energy *
- Entropy and Used Energy *
- Enthalpy and Available Energy *
- Entropy and Available Energy *
- Efficiency and Used Energy *
- Efficiency and Available Energy *
- Used Energy and Available Energy *

***** *Efficiency calculations only valid for points after first data point*

The GPSteam Properties Calculator is valid for all points defined by the pressures between the triple point and 15,000 psia, and temperatures between the triple point and 1500°F. In a saturated region, all properties are defined for values of quality between 0% and 100%.

The following list gives the specific operational ranges for the state points.

- Pressure: 0.0887-15,000 psia (0.006-221.20 bar)
- Temperature: 25.002-1600°F (-3.9-871°C)
- Enthalpy: 0-1860 Btu/lbm (0-4326.4 kJ/kg)
- Entropy: 0-3.0 Btu/lbm °R (0-12.560 kJ/kg K)
- Quality: 0-1

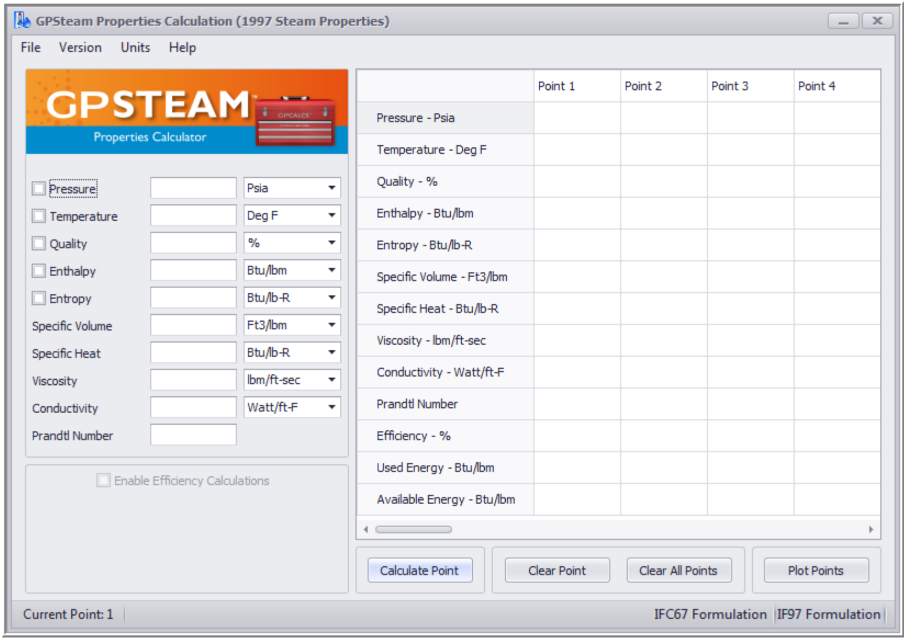
Note *The ranges given are for general information. There may be various combinations of parameters that will not return a valid result, such as certain calls in the wet region and near the critical point.*

Using the GPSteam Properties Calculator

Thermodynamic Properties of a Given State Point

1. Click the **GPSteam** icon in the GPCALCS program group to display GPSteam Properties Calculator (refer to **Figure 18-1**).
2. To define a set of thermodynamic properties for the initial state point, choose a pair of thermodynamic properties by checking the box next to those two properties. The other properties that do not form valid combinations with the first property selected are disabled. Unchecking the property boxes restores the other properties.
3. Use the **Units** drop-down box to select the appropriate unit set, if necessary.
4. Enter the pair of values in the property values entry fields. Use the drop-down list to choose its units, if necessary.
5. Click **Calculate Point**. The values of the remaining properties display in the property value boxes and in the **Point 1** column.
6. Units for each property value can be changed using the drop-down list box next to that value. When new units are selected, the value in the corresponding property value field is converted to the new units. You can select a consistent set of units, either English or SI, from the **Units** drop-down menu or save and load a custom set of units.

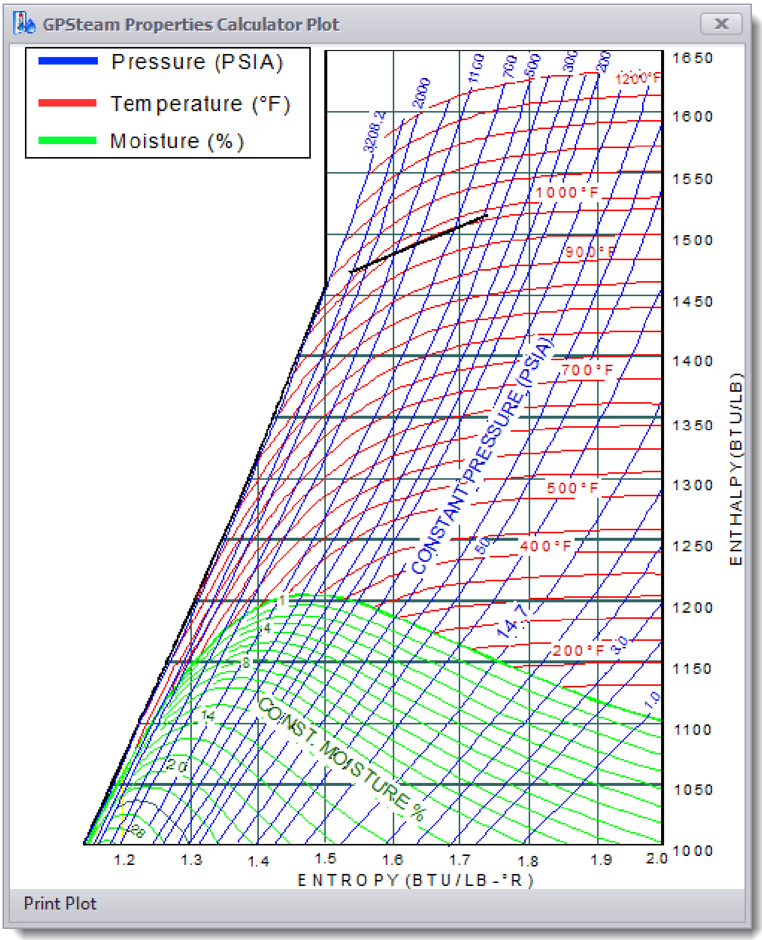
Figure 18-1
GPSteam
Properties
Calculator



7. Up to three additional state points can be calculated. Click in the first cell in the **Point 2** column to clear the results for the first point in the property values entry fields. Repeat **Steps 2** and **3** to add the second point.
8. To plot the state points on the ***Mollier diagram***, click **Plot Points.** The points display on the Mollier diagram (refer to **Figure 18-2**).
9. You can zoom in on its position by holding down the mouse button and dragging the box across the area you wish to enlarge.
10. **To remove the results in any Point column**, click a cell in that column and then click **Clear Point.**
11. **To save the defined state points**, click **File|Save** to display the *Save As* dialog. Navigate to the location where you want to save the ***.stm** file. Give the file a name or click on an existing file name. Then click **Save.**
12. **To view previously defined state points**, click **File|Open** to display the *Open* dialog. Navigate to the location where you saved the ***.stm** file. Type the name of the file or click on the file name. Then click **Open.**

Note *Opening a *.stm file will erase all values currently displayed in the GPSteam property value boxes and Point columns of the grid.*

Figure 18-2
Mollier Diagram

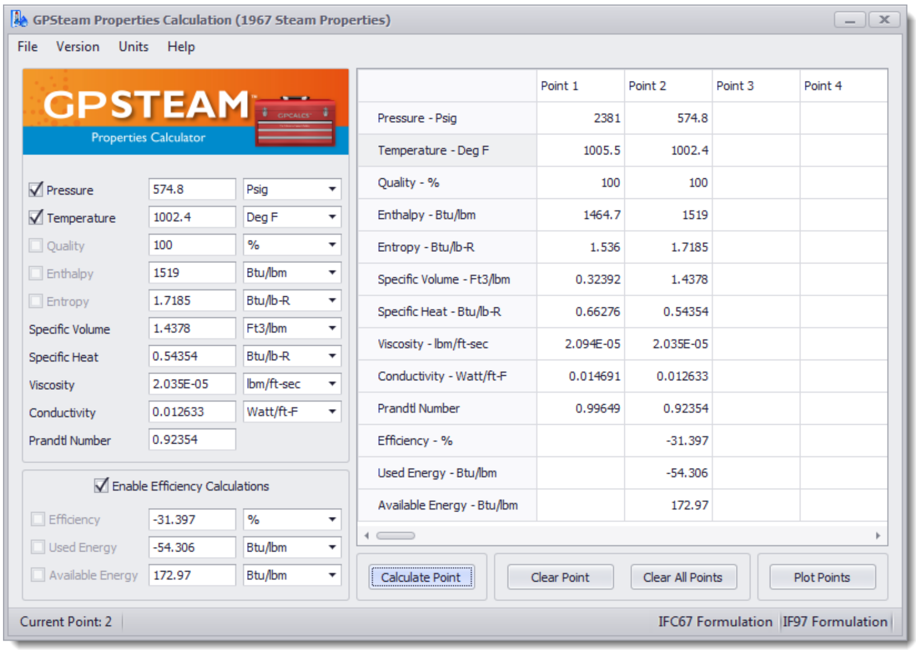


Enthalpy-Drop Efficiency Calculations

1. To calculate the enthalpy-drop efficiency for the steam turbine, first define the state point for steam entering the turbine, click on **Point 1** column, check the **Pressure** and **Temperature** property boxes and fill in the measured values for the input steam temperature and pressure in the corresponding property value fields.
2. Click **Calculate Point**. The values of the remaining properties display in the property value boxes and in the **Point 1** column.
3. To define the state point for steam exhausting from the turbine, click on the first cell in the **Point 2** column to clear the results for the first point in the property values entry fields.
4. Check the **Pressure** and **Temperature** property boxes and fill in the measured values for the exhaust steam temperature and pressure in the corresponding property value fields.

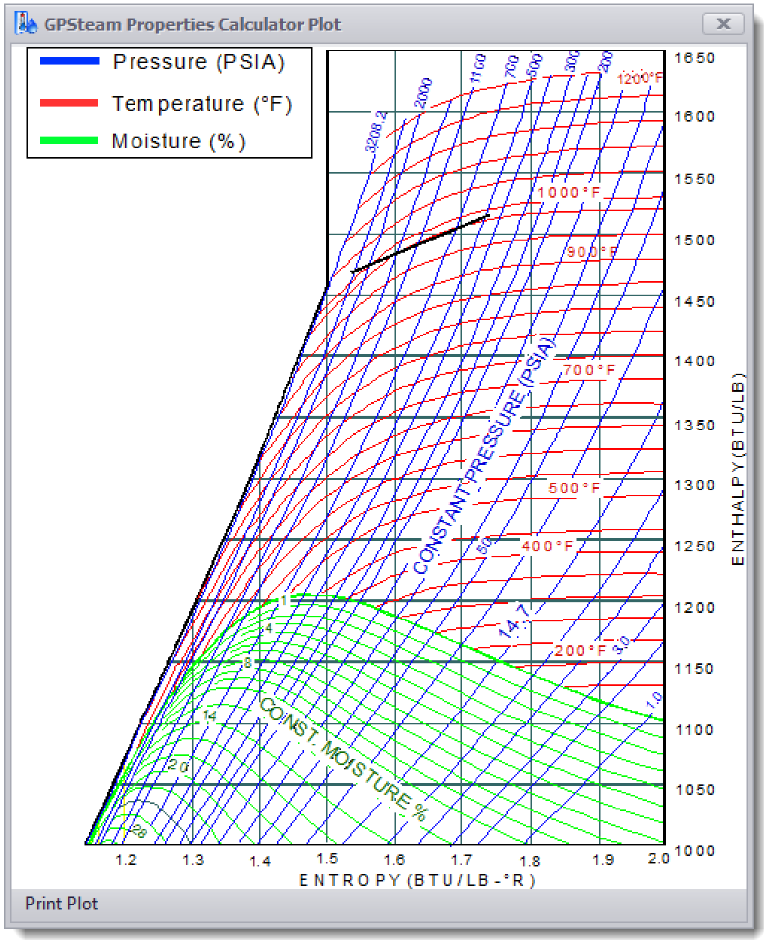
5. Click **Calculate Point**. The values of the remaining properties display in the property value boxes and in the **Point 2** column.
6. Check the **Enable Efficiency Calculations** check box.
7. Click **Calculate Point**. The values of the remaining properties display in the property value boxes and the values for efficiency, used energy, and available energy display in the property value boxes and in the **Point 2** column (refer to **Figure 18-3**).

Figure 18-3 Enthalpy-drop Efficiency Calculations



8. Click **Plot Points** to display the expansion line for the enthalpy-drop efficiency on the Mollier diagram (refer to **Figure 18-4**).

Figure 18-4
Mollier Diagram



19

Unit Conversion Utility

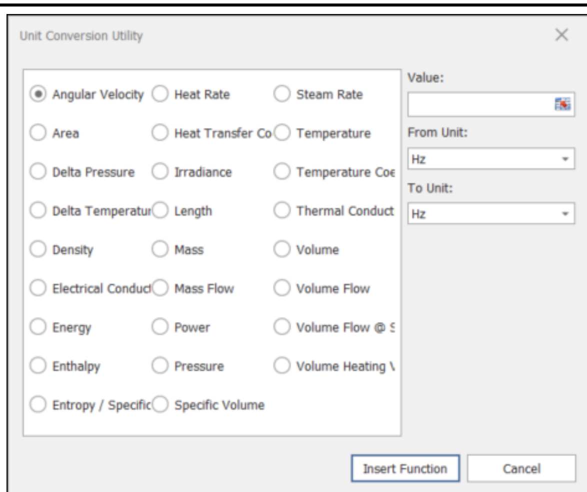
Unit Conversion Utility

Unit conversions are provided for automatic engineering unit conversion (both English and metric) for user inputs as well as any calculated values in the Excel workbook through the GPCALCS Utilities Add-in.

Using the Unit Conversion Utility in Excel

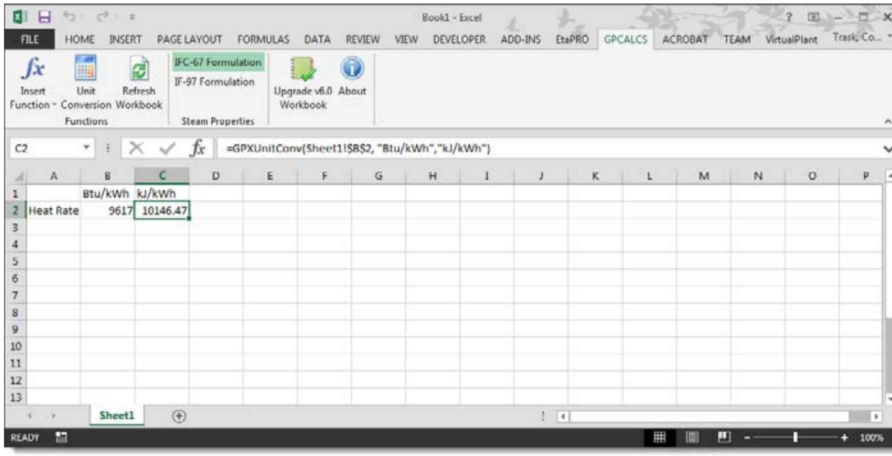
1. Open Excel and highlight the output cell on your worksheet.
2. Select the **GPCALCS|Unit Conversion** command.
3. The Unit Conversion Utility displays (refer to **Figure 19-1**).

Figure 19-1 Unit Conversion Utility



4. Click on the desired **Conversion Type** and then enter the **Value.** Use the drop down lists to choose the **From Unit** and **To Unit**. Click **Insert Function** when finished.
5. The converted value displays in the worksheet cell (refer to **Figure 19-2**).

Figure 19-2
Unit Conversion
Result



Handy Reference Library

Handy Reference Library

The *Handy Reference Library* workbook contains the following commonly used reference material displayed as a set of worksheets:

- Periodic Table of the Elements
- Principle Properties of Commercial Pipe
- Typical Coal Analyses with Dulong's Formula for HHV (Higher Heating Value) of Coal and Determination of Ultimate from Proximate Coal Analysis
- HHV to LHV (Lower Heating Value) Conversion for Fuels
- Typical Fuel Oil Analyses
- Typical Natural Gas Analyses
- Gas Properties
- Psychrometric Functions
- Engineering Unit Conversion Utility
- GPSteam Library Functions

Using the Handy Reference Library

1. Click the **Handy Reference** icon in the GPCALCS program folder. This opens the *Handy Reference Library* workbook (refer to **Figure 20-1**).
2. Choose the desired worksheet from the tabs at the bottom of the screen.

Figure 20-1
Handy Reference Library