March 30, 2020

Dear Customer,

We are pleased to release Version 29 of our software suite, with the new features and improvements summarised below. Some of the items described here were released as revisions to Version 28, optionally downloaded from our online Service Center.

Thermoflow Document Library

The software now includes a library of electronic books. It includes Dr. Elmasri's book entitled "Design of Gas Turbine Combined Cycle and Cogeneration Systems", the complete, massive four volume set of software manuals - about 3700 pages in total, and this 'Update Letter'. Use the [Help] - [Open Thermoflow Library] item from any main program to access and read the content. The entire document library is copyrighted, requires a Thermoflow key to be read, and disallows saving/printing the pdf's for copyright protection.

Features Added to Multiple Programs

Script Setup Wizard – Scripting is a very powerful feature built into GT PRO, GT MASTER, and THERMOFLEX. It allows you to extend the programs using logic you supply. Previously, defining scripts, even to do relatively easy tasks, was mostly in the purview of those steeped in the needed lingo, with time to experiment a bit. However, the new Script Setup Wizard makes it easy for anyone to use this powerful capability. The wizard leads you through a step-by-step process to produce an outline of your script, based on choices you make. Afterwards, you are left to fill-in the bit of code needed to accomplish your script's goal. The wizard has modes to (1) Create a script to produce a new custom model output parameter that's not naturally produced by the program. For example, adding two network massflows to produce a combined massflow. (2) Create a script that sets a model input parameter using your own logic. For example, defining a rule to determine when to run a GT inlet chiller, and when it should sit idle. (3) A combination of these two needs in a single script. The script wizard is available under the [Script] menu in GT PRO and GT MASTER, and under the [Define] menu in THERMOFLEX.

W-Style ACC – A new 'W-Style' air-cooled condenser configuration is available in all programs. The choice to use the original 'A-Style' or newly added 'W-Style' ACC is made on the [Main Inputs] tab of the Air-Cooled Condenser menu in design mode. Relative to 'A-Style', an equivalent capacity 'W-Style' condenser is shorter and lighter, thereby reducing structural steel requirements, foundation loads, and cost.

Natural Draft Cooling Tower (NDCT) – The design-point sizing model was improved and the off-design calculation logic was revised. NDCTs may now be used behind steam turbines as small as about 70 MW. PEACE cost estimates and site plan layouts are now reported for GT PRO and GT MASTER models that include NDCTs. In STEAM PRO, STEAM MASTER, and THERMOFLEX, the modifications allow use of NDCTs with smaller steam turbines.

Gas Turbine Data Base – The gas turbine database was updated as shown below. Some of these engine models were included in revisions to TFLOW28 available from our online Service Center.

Engines added to the database

705 PW FT4000 60 (50 Hz)	706 PW FT4000 60 (60 Hz)	707 PW FT4000 120 (50 Hz)
708 PW FT4000 120 (50 Hz)		

709 SIE SGT5-9000 HL	710 SIE SGT6-9000 HL	
715 Kawasaki GPB17D	716 Kawasaki GPB80D	717 Kawasaki GPB180D
718 Kawasaki GPB300D		
711 MAN 20V36/44G (50Hz)	712 MAN 20V36/44G (60Hz)	713 MAN 18V51/60G (50Hz)
714 MAN 18V51/60G (60Hz)	719 MAN THM 1304-10N	720 MAN THM 1304-12N
721 MAN MGT6000-1S-02	722 MAN MGT6000-2S-01	723 MAN MGT6000-2S-02
724 MHPS H-100 (50Hz)	725 MHPS 701 JAC (2015)	726 MHPS 701 JAC (2018)

Reciprocating Engine Data Base - The reciprocating engine database used by THERMOFLEX, RECIPRO, and NOVO PRO was updated to include models for the following gensets. These engines were included in revisions to TFLOW28 available from our online Service Center.

444 Jenbacher J920 (50Hz)	446 MAN 20V36/44G (50Hz)	448 MAN 18V51/60G (50Hz)
445 Jenbacher J920 (60Hz)	447 MAN 20V36/44G (60Hz)	449 MAN 18V51/60G (60Hz)
450 WinGD 9X62DF (50 Hz)		

PDE / GT PRO / GT MASTER / PEACE

Major Internal Restructuring - Substantial effort was invested to revamp the structure and calculation engines used by these programs to simplify their organization, reduce to a bare minimum the portions using ageing programming languages, make the programs easier to maintain in future, and prepare them for possible transition to entirely different computing platforms. Most of this massive effort is 'under-the-hood', barely noticeable, except that longtime users will observe a slightly different "look and feel" and a doubling of calculation speed. This restructuring ensures these programs continue to support your needs well into the future.

Gas Turbine Off & HRSG Fresh Air Fired - GT MASTER now allows operating the HRSG with fresh air firing when the GT is off-line. This enhanced flexibility allows you to model cases where the HRSG is used to provide steam for a process when the GT is unavailable, or its power is unwanted.

User-defined Plant Net Power or Process Heat Output – GT MASTER now includes a Duct Burner Operating Mode that automatically fires the duct burner to achieve desired net plant power for condensing combined cycles and back pressure combined cycles. It also includes another mode to automatically fire the DB to achieve desired process heat output for GT+HRSG plants and back-pressure combined cycles. These options are available from the Duct Burner panel on the [HRSG Main Inputs] tab. Previously, these control schemes were only available by user-defined "Control Loop" which lengthened computation time.

THERMOFLEX / PEACE

Fuel Cell Icon – A fuel cell system model was added for THERMOFLEX/PEACE licensees. The component includes a small library of commercially available units together with ability to create user-defined fuel cells. The icon, located

on the [Gas / Air] tab, has connections for gas fuel supply, combustion air source, flue gas exhaust, and optional connections for low or high grade heat rejection. The model predicts performance and estimates cost.

Electrolyzer – A new component that produces hydrogen and oxygen from water, using electricity, is available on the [Other Fluids] tab. This icon models a standalone electrolysis unit using a Proton Exchange Membrane (PEM). The model includes a small built-in library of commercially-available units, courtesy of Siemens. It also includes a User-Defined Electrolyzer option. The model computes hydrogen and oxygen production for a given power input, or power consumption needed for a desired hydrogen production rate. The output includes estimated system cost. Generous assistance by Siemens in characterizing their equipment is greatly appreciated.

Steam Methane Reformer – A new component to reform natural gas mixed with steam to produce hydrogen and CO, using heat from burning fuel, is available on the [Other Fluids] tab. This component models the core conversion process at the heart of a complete SMR plant, typical of those used to produce about 95% of the world's output of industrial hydrogen. The component is intended for use in building plant models that include heat recovery from flue gases and hydrogen-rich product streams.

Gas / High Pressure Air Heat Exchanger Icon – An HRSG component, used to heat/cool compressed air, was added to the [Boilers/HRSGs] tab on the icon bar, for THERMOFLEX/PEACE licensees. This icon, similar in utility to all other HRSG heat exchangers, may be included in HRSG assemblies. A use of this icon is to transfer heat from gas turbine cooling air to the flue gases passing through the HRSG. Sample file `(S2-39) HRSG with HPAirHX.TFX` illustrates this scenario.

Wet-surface Air Cooler Icon – This new heat exchanger is generally similar to the wet-surface condenser that has been available for many years in GTP/GTM/TFX, except that the substance being cooled is a liquid stream (water or heat transfer fluid) rather than condensing steam. It models an air-cooled wet-surface cooler in which hot liquid flows within horizontal tubes, over which water and air flow downward, the water being sprayed from above the tubes and the air being drawn by an induced draft fan. Gravity collects the water in a sump beneath the tubes from which it is re-circulated, whilst the air is reversed in direction to be expelled vertically upward by the fan. The model predicts cooler thermal performance, auxiliary load for the fans, size, weight, and cost of the complete cooler system. It is available to licensees of THERMOFLEX/PEACE.

'Adiabatic' Furnace with Grate – A new furnace icon, burning solid fuels to produce flue gas, without generating steam, is now available on the [Boilers/HRSGs] tab. This component includes nodes for fuel supply, under-fire and over-fire air, flue gas recirculation, and grate-cooling. The exiting flue gas can be cooled in separate radiant and/or convective heat exchangers placed downstream from this combustor in the THERMOFLEX network. The assistance of LAWI Engineering GmbH, Germany, in establishing geometric defaults is appreciated.

User-Defined Phase Change Fluid – The refrigerant fluid list now includes a new 'User-Defined' option. It allows you to provide your own thermodynamic properties for fluids not included in the THERMOFLEX or NIST database. Thermodynamic properties are entered on a specially built input menu similar to that used to define LNG fuels. All thermodynamic data is user-defined, typically by pasting data in from an external data source. During system calculation, whenever user-defined property data are needed, THERMOFLEX interpolates within the user-defined dataset to retrieve values. *THERMOFLEX relies entirely on the data you enter to represent the behavior of the fluid!* Therefore your data needs to cover a sufficiently wide Pressure-Temperature range, the curves should be smooth, internally consistent, and have sufficient resolution to enable a successful calculation. A plotting feature is available

from the data input menu to review entered data on various diagrams (T-s, P-h, etc.) to ensure the specified input data are smooth and well-behaved.

Master Control Loop – A new feature was added to aid solution of models with two interrelated control loops. Now, one control loop can be declared to be the 'Master'. During calculation, THERMOFLEX adjusts parameters for the 'Master' loop only after the other control loop has converged. This gives you control over the order the interdependent loops are executed, to help ensure they both converge to the desired result. `Sample file (S2-40) Master Control Loop.tfx` illustrates this feature. This model is configured to simultaneously achieve desired DH final water temperature and net plant power from a GTCC that heats DH water using steam from the steam turbine, which also contributes to the net power generated.

REFPROP Version 10 – The software now uses REFPROP Version 10. If you need NIST REFPROP material properties, you'll be prompted to download and install this particular software feature from our online Center. See [Help] – [Download TF REFPROP] for instructions.

Electric Heater – A new icon that heats streams using electricity is now available on the [General] tab. This icon provides similar functionality to its cousin, the Heat Adder. However, in this case the connected stream can only be heated, never cooled, and the energy used is accounted for in the plant's auxiliary power consumption, by default.

Solar PV – The Solar PV model was revised as described in the NOVO PRO section below.

Windfarm – The Windfarm model was revised as described in the NOVO PRO section below.

Battery – The battery model was revised as described in the NOVO PRO section below.

Others – Prices for desalinated water, fuels, and other streams exiting the model are now set on the relevant process and sink icons, rather than at the [Economics] menu. Mixer fractions for fuels and gas/air mixers may be set on a mole basis. A new switch to suppress gaseous fuel condensation messages is available on the [Current Settings] menu.

STEAM PRO / STEAM MASTER / PEACE

Steam Turbine Tuning – The Steam Turbine Tuning feature that was previously only available in GT MASTER and THERMOFLEX is now included in STEAM MASTER. This feature is accessed using buttons on the [ST Controls] tab on the [Steam Turbine] topic.

Flue Gas Cooler – A new ability to bypass HP FWHs is now available to supplement the ability to bypass LP heaters.

Evaporator Drum Steam - Steam from the boiler drum may now be selected to provide process steam, heat feedwater, and/or to run the steam air heater.

Steam Air Heaters – Models without flue gas air heaters may now have two steam air heaters on each of the primary and secondary air streams. Each heater may be fed by its own steam source from an appropriate location in the cycle. Previously, the model supported only one SAH on each of the primary and secondary streams.

NOVO PRO

Thermoflow Suite 29 includes NOVO PRO Version 1.7. The following is an overview of improvements introduced since NOVO PRO's initial release, at the end of 2018.

Hydrogen Production

An option to include one or more Electrolyzers in the NOVO PRO plant is now available. Electrolyzers are powered by excess renewable energy. They produce hydrogen exported from the NOVO PRO system at a price you specify.

Wind Data

Worldwide wind data is available for download from our online Service Center (https://www.thermoflow.com/ServiceCenter/TFWR). This data is based on ERA5 reanalysis data made available by the European Union's Copernicus program.

Wind data, for the same TMY locations included in the built-in the solar irradiance database, is also available for download from our online Service Center. Data is available for 2400 sites for the years 2000 to 2018.

Plants Only Mode

The [New Session] topic now has a 'Plants Only' mode that allows you to build a system consisting of any combination of renewable, storage, and/or thermal plant. NOVO PRO computes the power generated (or consumed) for the plants you define, using the loads you assign to them. 'Plants Only' mode makes NOVO PRO easier to use for single plant development and analysis, and is akin to how its cousin, THERMOFLEX, is used to model systems, except that NOVO PRO always computes techno-economic performance for an entire year.

Economics

Default values of financing assumptions were revised. An input for 'Investment tax credit, % of total project cost' is now available.

Battery

You can now choose between Lithium Ion, Lead Acid, Sodium Sulphur, and User-defined batteries. Performance- and cost-related inputs are initialized with values appropriate for chosen battery type. The automatic degradation estimate is also dependent on the selected battery type. Default inputs for Sodium Sulphur batteries are appropriate for those produced by NGK INSULATORS, LTD. and distributed by BASF. The generous support of these companies is appreciated.

Solar PV Plants

Default inputs for newly added plants were revised. The cost estimate was updated to better reflect current average costs for US-sited, utility-scale projects.

Solar insolation may now be user-defined on a monthly basis as a third way to specify the solar resource.

The solar field now includes one dimensional tracking with optional backtracking. It also includes ability to model arrays that use seasonal or monthly tilt adjustment.

The AC/DC inverter now uses a variable efficiency model by default. It reports the CEC and EU weighted efficiencies on output. The inverter model also includes capacity derating for operation in hot ambient conditions.

Inputs are now available to include far-field shading effects, and losses for high incident angles.

A number of new output reports are available to characterize solar PV field capacity and performance for the year.

Wind Farms

A wind turbine database including specs for 55 machines from eight manufacturers spanning the power range 200 to 9500 kW is now included to augment the user-defined turbine option.

A new [Turbine Count & Layout] tab is included with inputs to define how turbines are arranged on the site. A number of easy-to-define geometric arrangements are available along with a user-defined layout option where the location of each turbine is specified independently. An automatic method to estimate the performance reduction due to turbine-to-turbine interference is now included by default. An option is also available to user-define this factor using data you provide.

The cost estimate was updated to better reflect current average costs for US-sited, utility-scale projects.

Two methods to account for wind turbine availability were added. The first applies a user-defined average outage percentage to the entire farm, for the whole year. The second applies a user-defined number of turbine outage days per year. These outages are scheduled by the program, uniformly throughout the year.

A number of new output reports are available to characterize windfarm capacity and performance for the year.

Thermal Plant Dispatch

Two new automatic dispatch methods are available to determine how thermal plants are used to makeup for a shortfall in generation relative to Demand.

Automatic dispatch, Import price ignored – Dispatch thermal plants for lowest operating cost, with minimum Import power. NOVO PRO finds the lowest cost operating configuration that satisfies Demand, if possible. If internal generators lack capacity to satisfy Demand, Import power is used to makeup for the unavoidable shortfall. In this mode, Import power is only used as a last resort, never because it is cheaper than self-generation. Operating cost considers running fuel costs, startup fuel costs, and variable O&M.

Automatic dispatch, Import price considered – Dispatch thermal plants for lowest operating cost, using Import power if it's cheaper than self-generating. In this mode, the system thermal generators compete against each other, and also the grid to find a lowest-cost operating configuration. This method is useful to model grid-connected systems where relatively small Demand shortfalls can be offset by importing power, instead of a less-economical choice to start and run a thermal plant at relatively low load where it's inefficient.

Spinning Reserve – In addition to the optimized dispatch methods described above, any thermal plant may now be declared to operate in spinning reserve duty for any hour(s) of the year. When chosen, the plant is operated at its minimum load or higher depending on prevailing need for thermal power to satisfy Demand.

PEACE

Gas turbine prices for particular engines were revised based on informal feedback from some OEMs. Other engine prices were left unchanged from Version 28. Due to ongoing pricing pressure in the power generation equipment market, steam turbine pricing was reduced by 5%, while other specialized equipment pricing was left unchanged from last year. Pipe and fitting prices were revised to reflect trends in BLS data. Labor prices and miscellaneous equipment and material prices were increased, in the range of 4 to 6%, to reflect strength in the building market. In a case with unchanged GT price, the EPC price for typical 2x1 RHT GTCC is about 2% higher in Version 29 compared with Version 28. However, this will vary with plant details.

Reference currency exchange rates, relative to the USD, and regional cost multipliers were revised.