Thermal Tracking CHP And Gas Cooling

What does the future hold for on-site combined heat and power (CHP) systems? The authors think the present is steering toward smaller, integrated, and prefabricated systems, better use of available waste heat, and hot oil used for high-temperature heat recovery. The idea is to improve equipment life expectancy and efficiency, quicken startup, and lower overall installation costs.

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Fully dedicated on-site combined heat and power (CHP) systems present both challenges and opportunities for large multi-building projects; particularly when employing a combined cycle approach in the 3 to 20 MW range[1]. While some distributed power generation systems hedge their bets through reliance on both the sale and export of power (e.g., paralleling with a serving utility to achieve favorable economics), disappointing de-regulation benefits and the failure of energy trading to smooth out power supply vs. demand cost uncertainty has been a sobering experience for many customers.

Recent rethinking by concerned CHP designers has focused on exploring smaller footprint alternatives to the use of higher cost heat-recovery steam generators (HRSGs). One such approach involves use of prefabricated and fully integrated steam generators. These units come complete with associated heat exchangers, controls, and pumping systems employing low pressure, non-volatile, recirculating heat transfer fluids (HTF) capable of direct heat extraction of turbine exhaust gas waste heat to generate steam and allow cascading of the remaining captured waste heat to drive absorption chiller(s). They also include space and domestic hot water heating systems enabling greater utilization of available heat reclamation potentials in satisfying highly variable annual building power, heating, and cooling load demands.

Thermal tracking CHP utilization can be optimized through maintaining favorable log-mean-temperature-differentials (LMTDs) at the turbine gas extraction coil, also resulting in a lower exhaust gas temperature discharge to ambient. Various examples of such alternative HRSG cycles will be presented for gas turbine driven chiller and/or generator application, as well as gas turbine combined cycle operation to demonstrate the operational versatility and life cycle benefits of this approach for the above referenced range of commercially available gas turbines.

THINKING OUT OF THE BOX

Design Build Systems (DBS) is actively involved in exploring cost-effective CHP systems that are more user-friendly to the highly variable load demands of building occupancy, often requiring simultaneous space heating and cooling.

Currently, the conventional wisdom seems to look at employing a downsized version of utility type generation plants for buildings. Does this really make sense? Accordingly, the design engineer is faced with selecting all individual system components and matching engine or turbine-driven electric generation prime movers with their respective interconnected engine muffler, heat exchanger, or gas turbine HRSGs, single or two-stage absorption chillers, or combined-

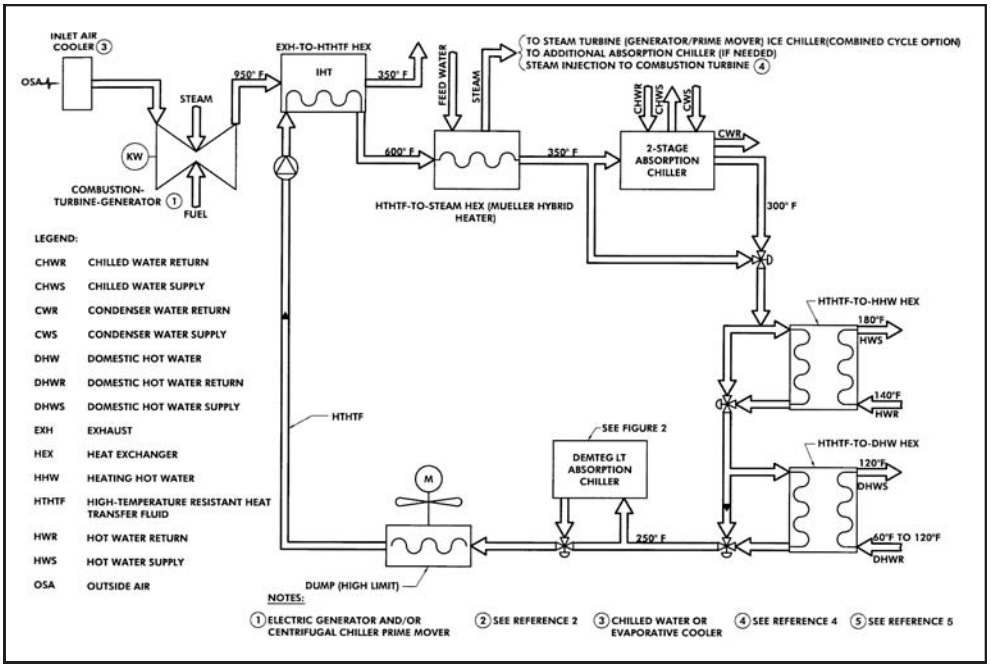

FIGURE 1. HTHTF piping diagram.

cycle steam turbines for larger gas turbine applications to meet client requirements.

In the public and private sector, where competitive bidding practice dominates, the designing A/E firm can expect to face time pressures from unpredictable equipment substitution(s) proposed by successful contractors under separate pressure to also reduce their cost. Often the result is diminished performance and accordingly a recognized greater risk and reluctance for the designing A/E firm to consider use of a CHP design strategy for its building project.

A/E firms and clients who recognize the benefits of CHP for their projects have alternatives to the use of HRSGs, particularly for larger building programs with highly variable diurnal thermal loads. One such approach involves the use of smaller-footprint, prefabricated steam generators mounted on modular skids functionally integrated with associated controls, heat exchangers, pumps, piping, etc., and arranged to recirculate non-volatile, low pressure HTF capable of direct extraction of turbine waste heat to generate either high-, medium- or low-pressure steam while enabling the remaining waste heat content of the exiting heat transfer fluid to cascade through absorption chiller(s), space, and domestic hot water heating systems. Use of this available waste heat results in greater utilization of CHP cycle heat reclamation potential through higher LMTDs across turbine extraction coils, while more closely tracking highly variable annual building heating, cooling, and power demands.

HEAT RECOVERY VIA HIGH-TEMPERATURE HEAT-TRANSFER FLUIDS

The proposed integrated CHP and gas cooling system[2,5] (ICHP/GCS) illustrated in Figure 1 incorporates a hot-oil high-temperature heat-recovery system interconnected with a modified gas-turbine-driver which is capable of powering either an electric generator, screw, or centrifugal chiller (not shown).

The proposed new configuration shown utilizes the waste heat from the gas turbine driver exhaust at approximately 950°F passing through the Industrial Heat Transfer, Inc.'s (IHT) coil on its way to ambient at approximately 350° (or lower, depending upon condensation constraints). This heat is captured by recirculating high-temperature resistant heat transfer fluid (HTHTF) also passing through the IHT coil located in the ducted turbine exhaust also shown entering the IHT coil at approximately 250° (or below) and discharging at approximately 600°.

The HTHTF is then utilized to generate either low-pressure steam (15 psig) for direct injection into combustion turbine (CT) gas/air fuel mixture and high-pressure steam if, for example, combined cycle operation as shown in Figure 4 is desired.

The HTHTF is then cascaded to serve building space and domestic hot water loads and where thermal energy storage (TES) is desired, a low temperature absorption chiller interconnected as shown in Figures 1 and 2. This cascaded approach for use with programmatic, simultaneous building heating and cooling requirements maximizes the utilization of the gas-fueled energy source required by the CT driver by achieving a high log mean temperature differential (LMTD) across the IHT extraction coil.

This technology also enhances the potential for a "plug and play" trigeneration system approach without the necessity of providing a licensed 24/7 operator when operating in the low-pressure steam modality, while avoiding the need for a large footprint, costly utility type HRSG, both of which have become major cost barriers to implementation of gas turbine type CHP building facilities.

What was unique about the ICHP/GCS is being able to employ a commercially available HTHTF operating at high temperatures up to 600°. These HTHTFs offer a number of benefits for gas-fired CHP building systems as discussed in this paper. The HTHTF itself is a highly efficient, thermally stable, cost-effective, nontoxic, safe to use, and easy to dispose of fluid with a high heat transfer coefficient and low pressure drop due to friction.

Unlike conventional heat-transfer fluids, use of Paratherm HE does not cause hard carbon formation on heated surfaces. Without layers of carbon building up, the common problems of heat transfer and flow impairment are eliminated. In addition, the problems of carbon chunks breaking loose, circulating through the system, impeding flows, and fouling components are also avoided. Although small carbon granules form in the fluid when over-heated, these granules remain in suspension and are generally filtered out.

Additionally, the selected HTHTF for our subject case studies operates at a low vapor pressure, which is less than one psia at its planned maximum operating temperature of 600°. This feature combines with the fluid's characteristic low pressure drop to provide the CHP building plant designer considerable latitude in being able to choose lower overall cost equipment, as opposed to employing conventional slow-reacting and costly HRSGs.

For example, Table 1 shows a comparative first-cost analysis of conventional HRSG and ICHP/GCS alternatives for waste heat extraction of turbine exhaust waste heat for two commercially available solar gas turbines. Actual vendor quotes were used for each alternative.

Notice that both alternatives are expressed in the basis of $/kW and reflect a sizable cost savings; namely: approximately $270,000 or $53.24/kW for an ISO-rated Taurus model and $410,000 or $39.28/kW for an ISO-rated Mars model, respectively. In short, substitution of the proposed IHT and APV HEX's for comparably sized HRSGs amounted

Solar Turbine Model	kW	Hybrid HEX Cost					HRSG Cost		Cost Difference	
		Mueller HX Cost	IHT HX Cost	Accessory Cost	Total Cost	$/kW	Total Cost	$/kW	Delta Cost	$/kW
Taurus 60	5,071	$40,000	$140,000	$100,000	$280,000	$55.22	$550,000	$108.46	$270,000	$53.24
Mars 100	10,439	$60,000	$180,000	$125,000	$365,000	$34.96	$775,000	$74.24	$410,000	$39.28

TABLE 1. A first-cost analysis of conventional HRSG vs. ICHP/GCS alternatives.

to approximately a 49% to 53% cost savings. Furthermore, when one considers the additional advantages resulting from greater operating efficiency through increased overall annual waste heat utilization, use of the ICHP/GCS (in lieu of a HRSG) can represent a major cost breakthrough and gain toward achieving building sustainability.

When used for steam generation, the hot oil approach may also incorporate use of other commercially available heat transfer oils, such as: Santotherm –60, -66, -75, -VP1, or Bayer – KT 10, for example. When using heat transfer oils, depending upon operating conditions, their use may result in reduced total heat recovery due to pinch point issues.

However, all of the above referenced hot oils can also be used directly for equipment in which its temperature glide can be matched better, such as a heating system or an absorption chiller. Direct use of such hot oil HTHTFs can provide a better approach than use of steam, hot water, or direct firing of absorption chillers in CHP systems. Each of the latter more conventional approaches, when compared with direct use of above referenced HTHTFs, has its drawbacks. For example, use of steam reduces total potential recovered heat due to the pinch points, and direct exhaust firing of absorption chillers also involves very large ducts to transport the exhaust gases and generally involves greater backpressure on gas-fired turbines, which can also reduce available electric output.

HEAT RECOVERY OIL SYSTEM

The proprietary ICHP/GCS turbine exhaust heat extraction system, developed by DBS, circulates a HTHTF as shown in Figure 1. Heat is extracted from the turbine exhaust via a heat exchanger similar to IHT fin/tube exhaust heat exchanger extraction coils. The heat is transferred to the HTHTF and can be used first to generate steam, which can be used for steam injection, independently determined to improve thermal dynamic efficiencies by 10% to 15%[4].

After steam production, cooling is produced via an absorption chiller, then heating hot water, domestic hot water, and finally, if additional cooling is warranted, to a low-temperature absorption chiller using a diethylene methanol tri-ethylene glycol mixture (DEMTEG) (Figure 2). If additional waste heat is still available, TES can be used prior to rejecting to ambient via a dump heat exchanger as shown. The actual temperatures and flows will depend, of course, on the size and nature of the loads.

The HTHTF-to-steam hybrid welding plate heat exchanger currently planned for use is a commercially available hybrid heat exchanger, incorporating both shell/tube and plate heat exchanger characteristics and capacity can be scaled up or down fairly readily. It is currently manufactured by APV, and its use offers improvement versus use of conventional HRSGs when utilizing Paratherm HE or any of the above referenced HTHTFs.

Key advantages of the ICHP/GCS include:

- Lower heat-recovery heat-exchanger first costs as illustrated in Table 1;
- Greater thermodynamic cycle efficiency due to higher LMTDs;
- Greater power production due to less turbine back pressure;
- Better load tracking (full modulation);
- Quicker startup;
- Greater ability to handle typical building transients; and
- Improved life expectancy.

Because the HTHTFs are not under high pressure, HTHTF to steam HX construction requirements are not as stringent as with a typical HRSG. Using the HTHTF in series heat exchanger configuration shown in Figure 1 increases the overall LMTD, which allows for smaller heat exchangers, lower first cost, and less turbine operating backpressure. Lower turbine backpressure reduces gas turbine power loss; e.g., as shown in Figure 3, a 2-in. wc reduction on a Solar Saturn 20 reduces power loss by approximately 0.5%. Relatively colder return oil temperature also allows for lower exhaust temperatures and overall cycle efficiency improvements.

Some disadvantages of HRSGs when compared with the ICHP/GCS include:

- Cold start time delays reduce HRSG's ability to track cyclic rapid-system load variations;
- HRSG performance is subject to balance of plant (BOP) equipment (e.g., steam turbine operation);
- BOP logic is critical to HRSG temp and steam turbine pressure control at startup;
- Accurate BOP equipment operational temps are essential to HRSG fabrication;
- Use of exotic materials to withstand thermal cycling may be cost-prohibitive;
- Materials are able to endure plant cycling limited by current codes/standards;
- HRSG design for rapid temp changes encountered during cold start-up may be difficult[3]; and
- The need for costly "soak period" apparatus to reduce HRSG start-up time eliminated.

ADDITIONAL ICHP/GCS ALTERNATIVES

HTHTF fired indirect absorption chillers. Should steam production not be required, the hot oil can be used directly at 350° to produce cooling via an absorption chiller and then heating needs (space heating,

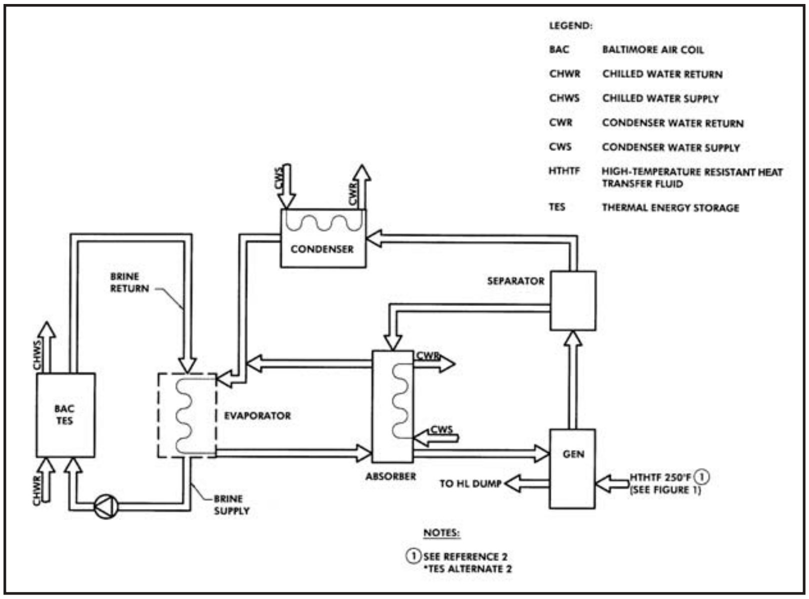

FIGURE 2. DEMTEG low-temperature absorption chiller.

domestic hot water production, etc.) via a heat exchanger. By eliminating high-pressure steam production, this could potentially reduce the need for a full-time operator.

Combined cycle options. Should building CHP loads and utility costs dictate the need for additional electric power vs. cooling production or heating needs, high-pressure steam can be used to drive a steam-turbine generator operating in a combined cycle configuration similar to that shown in Figure 4. Referring to Figure 4, notice that the gas turbine driver is interconnected by tandem shafts to both an induction motor/generator and a refrigerant compressor that is part of a mechanical chiller system. The operative steam turbine driver, by gearing and clutches shown in Figure 4, can drive either an electrical generator or the chiller compressor. With steam not available, the induction motor/generator can be used as a motor to drive the chiller only. The balance of the system remains the same as discussed above. With the 2005 California Title 24 currently not allowing credit for the use of waste heat from fossil burning sources (such as with an absorption chiller), both gas and steam turbine prime-mover-driven chillers[2] can provide a cost-effective path toward compliance.

SAMPLE SYSTEM

Actual CHP study results for the Goss Engineering (GEI) office project involved a 1.5-MW Kawasaki GPB15X gas turbine with an approximate heat recovery of 11 MMBtuh, coupled with a nominal 1,200-ton two-stage indirect Paratherm HE fired absorption chiller. In this example, 130 gpm of the HTHTF in the steam generator can produce up to 11,000 lb/hr, depending upon the steam pressure and condensate return temperature. The 300° HTHTF leaving the Broad direct HTF fired absorption chiller still had sufficient heat to generate several hundred gpm of hot water, depending upon the entering and leaving oil temperatures (e.g., if the absorption chiller is not being utilized, the HTHTF inlet temperature could rise to 350°, and lowering HTHTF temperatures below 250° increases the LMTD of the turbine exhaust heat extraction coil).

SUMMARY

DBS is now in the process of developing a user-friendly design optimization program to facilitate rapid analysis of user requirements to pre-select appropriate ICHP/GCS components and operating modalities. This then will allow CHP designers to proceed to a computer enabled design of one or more integrated skid-mounted systems for offsite fabrication and subsequent shipment for integration with gas (and steam) turbine driver(s), cooling tower(s), absorption/centrifugal chiller(s), with associated interconnecting piping, controls, etc., installation performed at the project site.

Claimed advantages of the above described ICHP/GCS are as follows:

- Much smaller thermal mass of oil and water in the system as compared with a HRSG, thus allowing much quicker response to varying thermal input;
- Low-pressure operation of the HTHTF loop. This reduces the mechanical requirements of the exhaust heat exchanger, making it more robust to thermal cycling;
- Relaxed mechanical requirements for the exhaust (IHT) heat

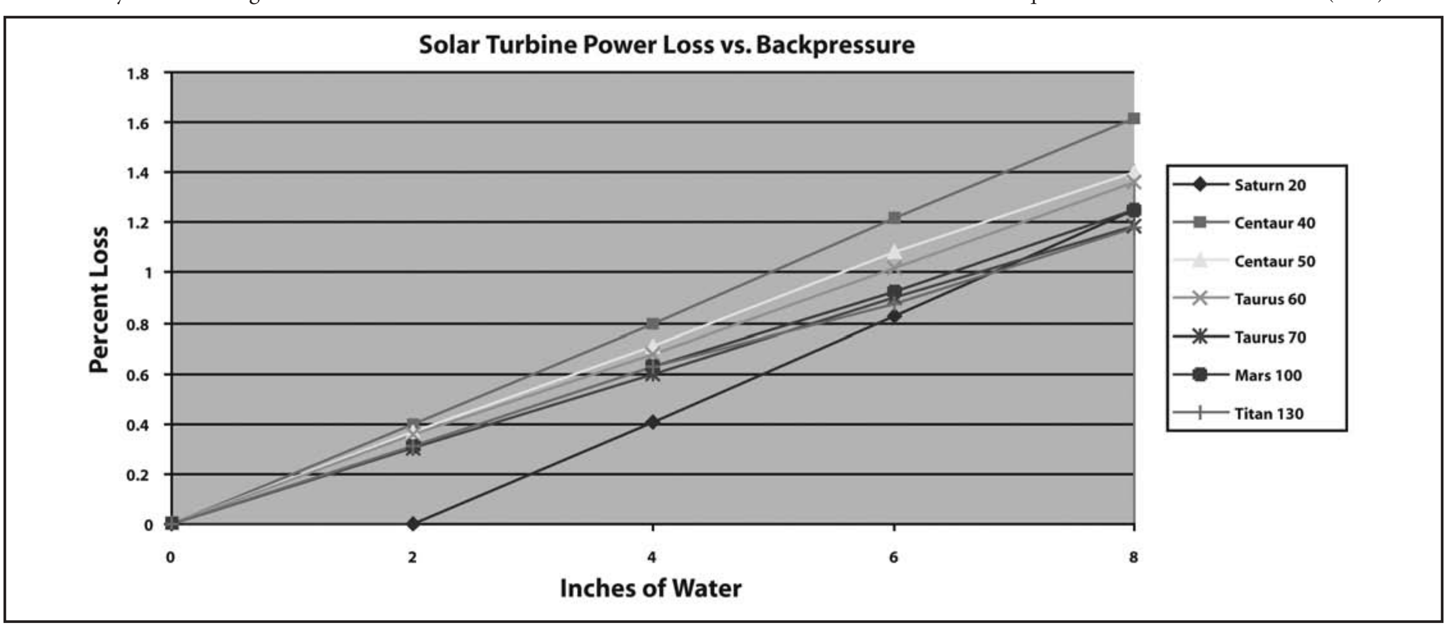

FIGURE 3. Solar turbine power loss vs. backpressure.

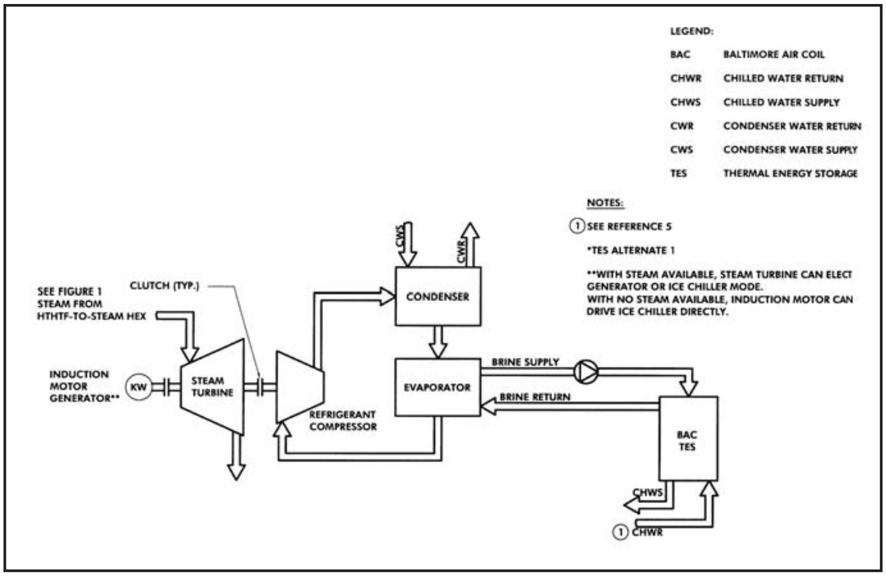

FIGURE 4. Steam turbine (generator/prime mover) ice chiller schematic.

exchanger and removing the steam generation from exhaust stream allows for more compact heat exchanger design;

- Reduced exhaust (IHT) heat exchanger pressure drop, which results in slight improvement in power generation; and
- Lower overall installation cost.

Finally, rising energy prices and environmental and power reliability concerns have a growing number of building managers and owners now considering "going it alone" with more user friendly on-site CHP systems. On-site CHP systems give FMs and operators generally unlimited options to manage their energy supplies as they see fit in their effort to reduce what they must pay to operate their buildings. For all of the above reasons and the advantages over conventionally designed HRSG-based CHP systems, ICHP/GCS offer increased flexibility in determining how much FMs will pay for power along with heating and cooling, as well as how to configure systems for maximum performance and minimum energy costs. **ES**

Meckler currently serves as president/CEO of Design Build Systems (DBS), headquartered in Los Angeles. He has published over 300 feature and technical articles, books, handbooks, videos, design and policy manuals including seven professional engineering books on energy conservation, IAQ, cogeneration, and CHP. In l995 he was elected as chairman of International Standards Committee ISO /TC 205: Building Environment Design, involving development of international standards for lighting, acoustics, energy, air quality, and building control systems representing 33 participating nations until 2001. Contact him at **mmeckler@designsystemsbuild.com**.

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