Life below the wet bulb: The Maisotsenko cycle

Today's combined-cycle power plants are attaining efficiencies near 50%. But a new technology promises levels of up to 60%. The Maisotsenko cycle—which seems to defy the second law of thermodynamics—uses souped-up cooling and captures significant amounts of energy from the atmosphere. The result is higher efficiency and lower emissions.

By Ken Wicker

For several years, the humid air turbine (HAT) cycle has promised a new way to generate electricity more efficiently and cost-effectively than combined-cycle power plants. However, practical limitations have prevented the HAT cycle from being commercialized. In response, Idalex Inc.—an R&D firm based in Arvada, Colo.—has developed and proven a new technology called the Maisotsenko (M) cycle that it claims solves the HAT cycle's limitations.

The major limitation of the HAT cycle lies in its humidification process, which uses a column saturator that ties evaporation to the boiling temperature of water at compressed air pressure. Raising humidity past this point would require a separate boiler—another piece of equipment whose cost, maintenance, and pressure and temperature losses are significant drawbacks.

According to researchers at Idalex, the M cycle lacks those drawbacks because in it, humidity gains are limited only by the amount of waste heat available from the turbine's exhaust gas. Leland Gillan, a senior R&D engineer at Idalex, claims that the M cycle could achieve efficiencies as high as 60% while simultaneously lowering emissions—all with lower equipment costs and a smaller footprint than the HAT cycle.

Gillan also claims that the M cycle can be scaled to work with any size turbine, from micro to large, and that it would not suffer from the drops in efficiency that conventional gas turbines suffer at partial loads. "Rather," he states, "the ability to add moisture using waste heat allows the Maisotsenko cycle to run at high efficiency at any load from 50% to 100%."

Although this new combustion turbine technology is still at the theoretical stage, it has some high-powered supporters. One, Dr. Myron Tribus, is a former assistant secretary for science and technology at the U.S. Department of Commerce. When he first studied the M cycle, he thought it violated the second law of thermodynamics. (One way to state the law is as follows: In a closed system, you can't finish any real physical process with as much useful energy as you had to start with—some is always wasted, in the form of entropy.) However, once Tribus understood what Idalex was doing and how the cycle works, he was impressed. "The Maisotsenko cycle should have many applications for increasing the efficiency of power systems," he says.

The new thermodynamic cycle is named for Dr. Valeriy Maisotsenko, Idalex's chief scientist. It gets its latent heat of evaporation from a heat and mass exchanger. Dr. Maisotsenko claims, "The cycle works at any temperature and pressure, and can dramatically improve any process that needs fluid cooling and/or saturated air."

Dial M for max efficiency

According to Idalex VP Rick Gillan, the company already is producing and selling a commercial air-cooling unit based on the M cycle. Notably, it has a SEER (seasonal energy efficiency ratio) of 40, making it three to four times more efficient than conventional air conditioners. Called the Coolerado Cooler, the unit is a heat and mass exchanger that cools air to within a few degrees of the dew point of ambient air while not adding any moisture to it.

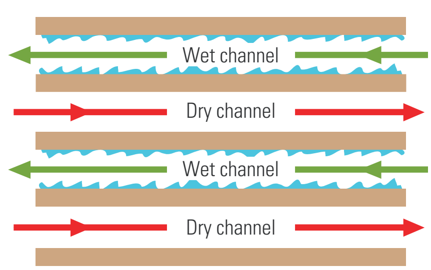
Idalex's prototype has been independently evaluated by the National Renewable Energy Laboratory's (NREL) Center for Buildings and Thermal Systems. Steve Slayzak, manager of thermal conversion projects for NREL and of the Department of Energy's distributed energy and electric reliability program, reports that "Idalex's [Coolerado Cooler] cooled below the wet bulb temperature without humidifying the process air or demanding excessive working/purge air that would eat up energy savings with fan power. As an advanced heat rejection technology," he continues, "the Idalex staged cooling concept is exciting for a number of applications."

Indirect evaporative air coolers work by passing one stream of "product" air over the dry side of a plate and another stream of "working" air over the opposite, wet side. The wet side absorbs heat from the dry side through evaporation, in the process cooling the dry side via the latent heat of vaporization. Ideally, the product air temperature on the dry side of the plate could reach the wet bulb temperature of the incoming air (Figure 1).

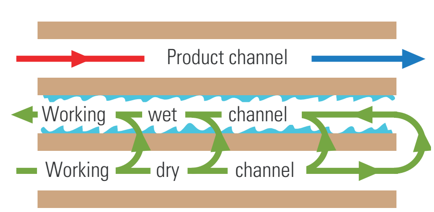
How does it cool?

Although the M cycle relies on the same principles as indirect evaporative coolers, its geometry and air flows are very different. The cycle uses a unique plate-wetting and channel system (Figure 2) that captures

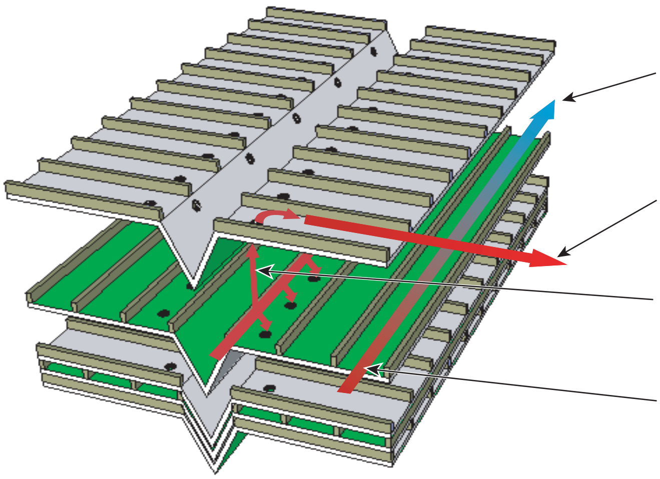
1. Way cool. Theoretically, counterflow indirect evaporative cooling, as illustrated here, could cool air to its wet bulb temperature. However, physical limitations have prevented prototypes from matching theory in practice. *Courtesy: Idalex Inc.*



2. M cycle. This simplified representation of the Maisotsenko cycle shows how it cools product air in incremental stages toward its dew point temperature while saturating the working air. *Courtesy: Idalex Inc.*



3. The Coolerado Cooler. A cross-section of the cross-flow heat and mass exchanger that powers Idalex's production Coolerado Cooler. NREL tests of the cooler showed that the product air temperature was well below wet bulb and approached 80% of its dew point while keeping absolute humidity constant. The tests also showed that the working air was at or very near its saturation point. *Courtesy: Idalex Inc.*



the potential energy available from evaporation to produce cooling temperatures within a few degrees of the dew point of the intake air. As the working air becomes saturated, its enthalpy rises, producing sensible heat loss in the product air. The cycle is a four-step process (Figure 3).

Leland Gillan says that the company has built commercial coolers that supply air near the dew point of ambient air and that they provide the added efficiency needed for compressor inlet cooling. The design of heat and mass exchangers intended for use in power-generating turbines uses the same principle as the air cooler: cooling turbine exhaust gases and humidifying the compressed air.

What does it mean to the industry?

The HAT cycle and the Maisotsenko Combustion Turbine Cycle (MCTC) have several goals in common. Both claim to increase power output and broaden the power band while maintaining high system efficiency by supplying added mass (moist air) to the turbine at no additional compressor work. Both also recover turbine exhaust heat by putting it back into the cycle and lower emissions by providing the combustor with moist air.

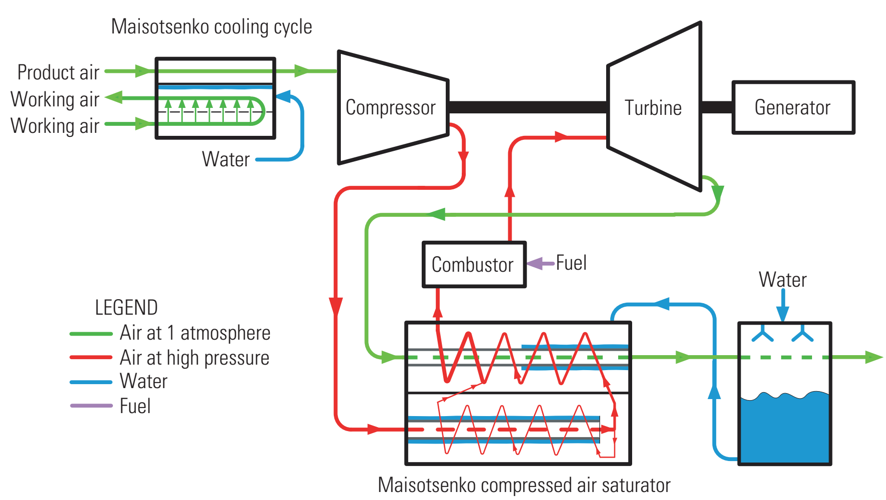
However, the MCTC goes a step beyond the HAT cycle by further increasing the moisture in the compressed air stream, which increases power and efficiency. In addition, the Maisotsenko cycle minimizes the size of the heat transfer surface, pressure losses, and capital cost by using a souped-up heat transfer process. Meanwhile, a Maisotsenko cycle air cooler can be used to increase compressor efficiency by supplying the compressor with cool air that has not had humidity added to it. This cooler air is easier to compress, which means less work for the compressor.

How does the MCTC work? It receives the hot, dry, compressed air and cools it toward its dew point temperature without adding humidity (Figures 4 and 5). This cool air extracts heat from the turbine's exhaust gases, bringing them to a lower temperature at which even more heat can be extracted. The cooled air is split into two streams. The first stream cools itself by being passed in counterflow to the air being cooled and by adding moisture to it through an indirect evaporative heat and mass transfer process. The second stream is then passed in counterflow to the turbine exhaust gas stream while evaporating water into the air again in an indirect evaporative heat and mass exchanger. The two high-humidity air streams are then recombined and sent to the combustor for heating before entering the turbine.

This process is very efficient, because with a relatively small temperature increase it is possible to add a tremendous amount of moisture to the air—30% or more—due to additional mass flow. Humid air, however, has a higher specific heat and takes more fuel to increase the temperature. However, the additional heat in the turbine exhaust gases allows additional water to be evaporated and more heat to be recovered.

By contrast, the HAT cycle (Figure 6) first cools the compressed air with water in a heat exchanger. This heated water supplies part of the energy and mass used to humidify the cooled air in a saturating tower. Additional heated water comes from

4. Maisotsenko Combustion Turbine Cycle (MCTC) with a Maisotsenko compressor inlet cooler. Idalex claims that a turbine based on this cycle could be 60% thermally efficient at any load from 50% to 100% and emit far less pollution than a conventional combustion turbine. *Courtesy: Idalex Inc.*



other heat exchangers. To work, the water must be in liquid form, rather than steam. This creates a pinch point where the water enters the tower and gets evaporated. One of the drawbacks of the HAT cycle is its need for these additional heat exchangers. The more exchangers needed, the greater the temperature and efficiency losses.

Much of the research on the HAT cycle has been based on joint studies funded by EPRI, Fluor Daniel, Texaco, and United Technologies. Although no official studies have compared the HAT cycle with the Maisotsenko cycle, studies comparing the HAT cycle with a combined-cycle system indicate that it could reduce capital costs because it doesn't need boilers, a steam turbine, a condenser, or a cooling tower. In addition, the large amount of humidity in the combustor air could reduce NO_x emissions to a very low level.

Complementary technologies?

Rather than view the HAT cycle and the Maisotsenko cycle as competing against each other for the efficiency grail, Dr. Bill Day, manager of outreach for the South Carolina Institute for Energy Studies, sees the two complementing each other. "If it works as claimed, the heat exchangers developed for the Maisotsenko cycle could reduce the cost of the HAT cycle because they are more efficient and simpler."

Another, more comprehensive view of the M cycle's prospects comes from Dr. Fred Robson, principal engineer at KraftWork Systems Inc. (Amston, Conn.). He says the key to the HAT cycle is getting the water vaporized at the lowest temperature feasible. "A humidifier using various bits and pieces of low temperature heat from the gas turbine cycle does the trick." Under certain conditions, the M cycle may have a thermodynamic advantage because it can get more water and consequently more mass into the turbine.

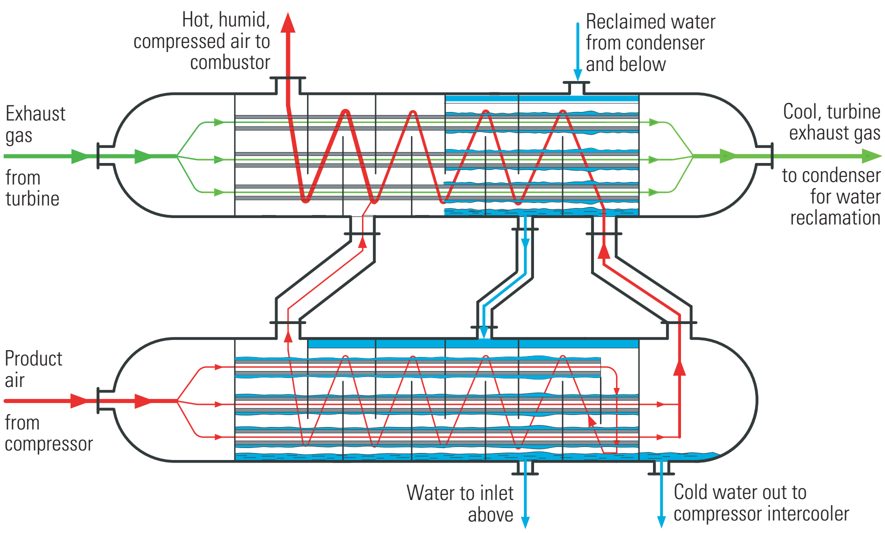
However, Dr. Robson adds that that putative advantage is highly dependent on engine specifics. "For a given compressor flow, the turbine (expander) may need to be resized to accommodate the additional flow of humidified air. Thus, if the expander cannot be resized to handle the additional moisture available from the M cycle, it could lose any thermodynamic advantage over the conventional humidifiers of the HAT cycle. The reason for this is simple. If the humidification level is constrained, the Maisotsenko cycle is not utilized to its full capability and would do the same 'duty' as a regular humidification tower." However, the Maisotsenko exchanger design allows varying amounts of water to be evaporated, making for a wider power band.

Consequently, the prospects for the M cycle boil down to its capital costs and system integration issues. Unfortunately, according to Dr. Day, "The economics of getting either system up and running are quite substantial."

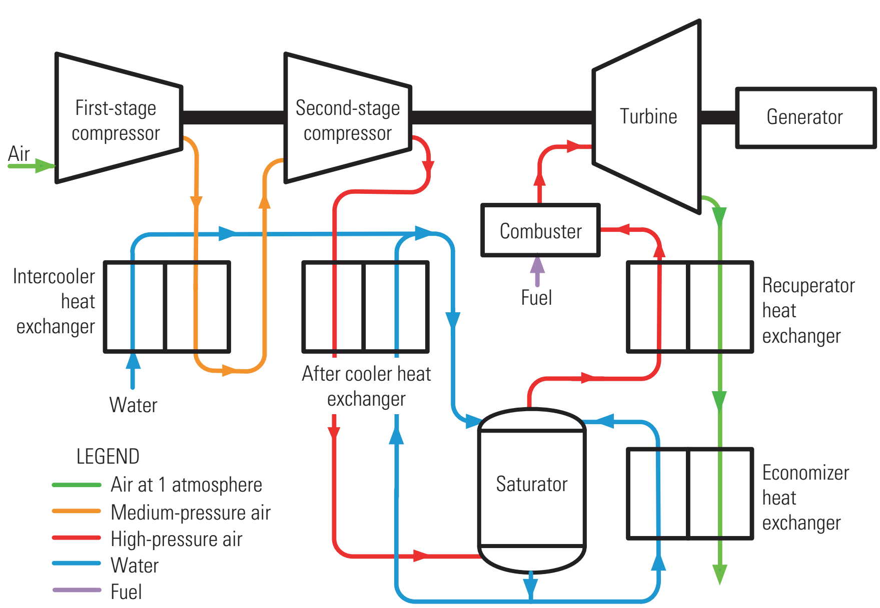
At this point, the Maisotsenko system is only in the conceptual stage. Meanwhile, only small HAT systems have been built for testing purposes at Lund University in Sweden. According to Dr. Robson, "It makes sense that for larger systems with higher output, the Maisotsenko cycle could very well perform better both in terms of thermodynamics and cost."

Though the HAT cycle uses three heat exchangers and a saturator to accomplish what the MCTC does with two higher-efficiency heat exchangers, at this point HAT is a much more evolved technology. The challenge for Idalex is to prove that the M cycle performs as claimed. The first test for the company will be to see if it can successfully market the Coolerado Cooler. Only then will it be able to set its sights on improving efficiencies and lowering costs for power turbine applications. For the final word, Rick Gillan says that "Idalex is currently seeking the funding needed to build a microturbine prototype based on the technology. If all goes well, we hope to do so and offer a commercial system based on it within three years." ■

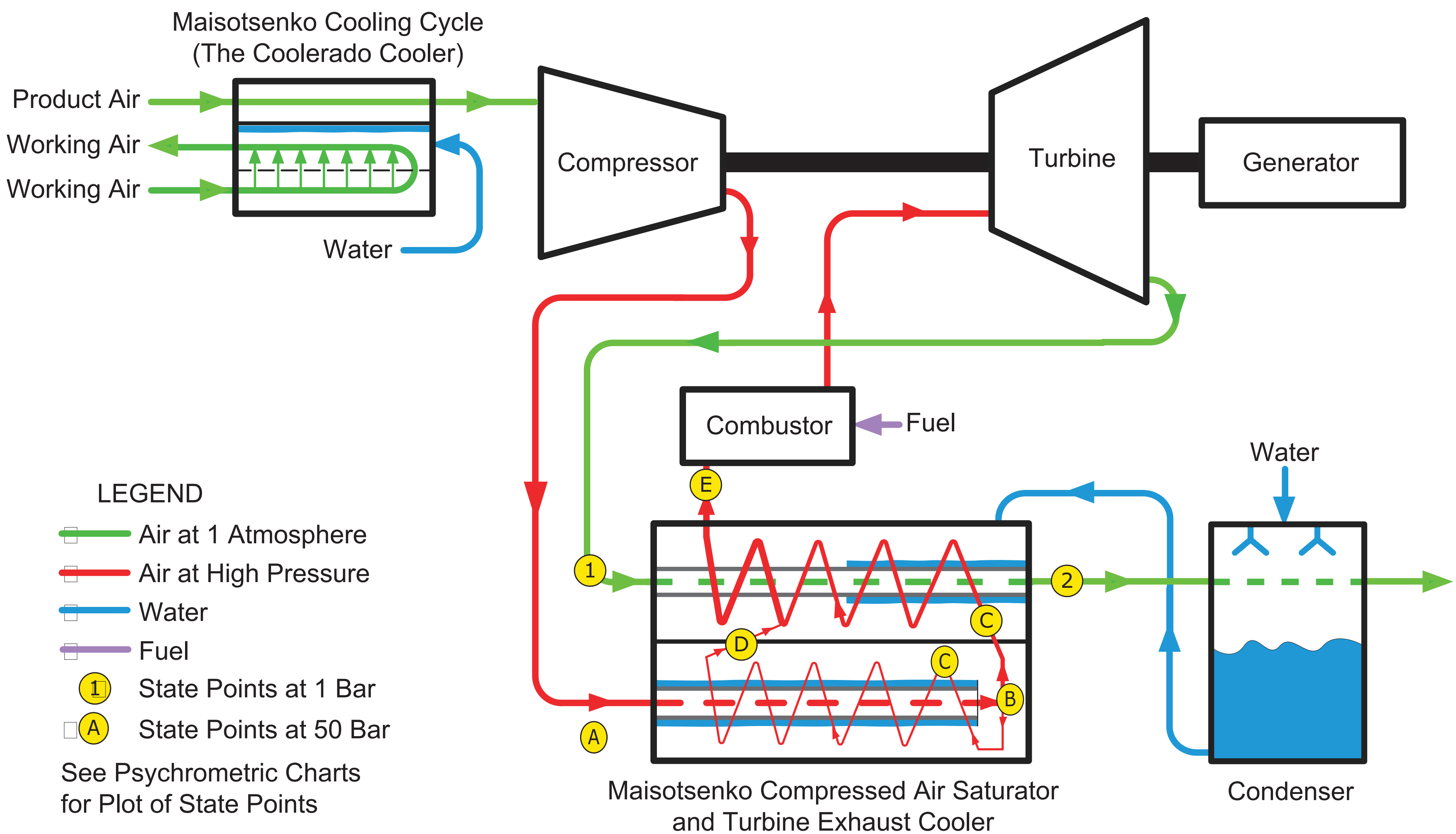
5. The Maisotsenko compressed air saturator/turbine exhaust cooler at the heart of the MCTC. Idalex claims this cooler, with its high-pressure shell and tube exchanger, can match the performance of low-pressure plate heat and mass exchangers. *Courtesy: Idalex Inc.*



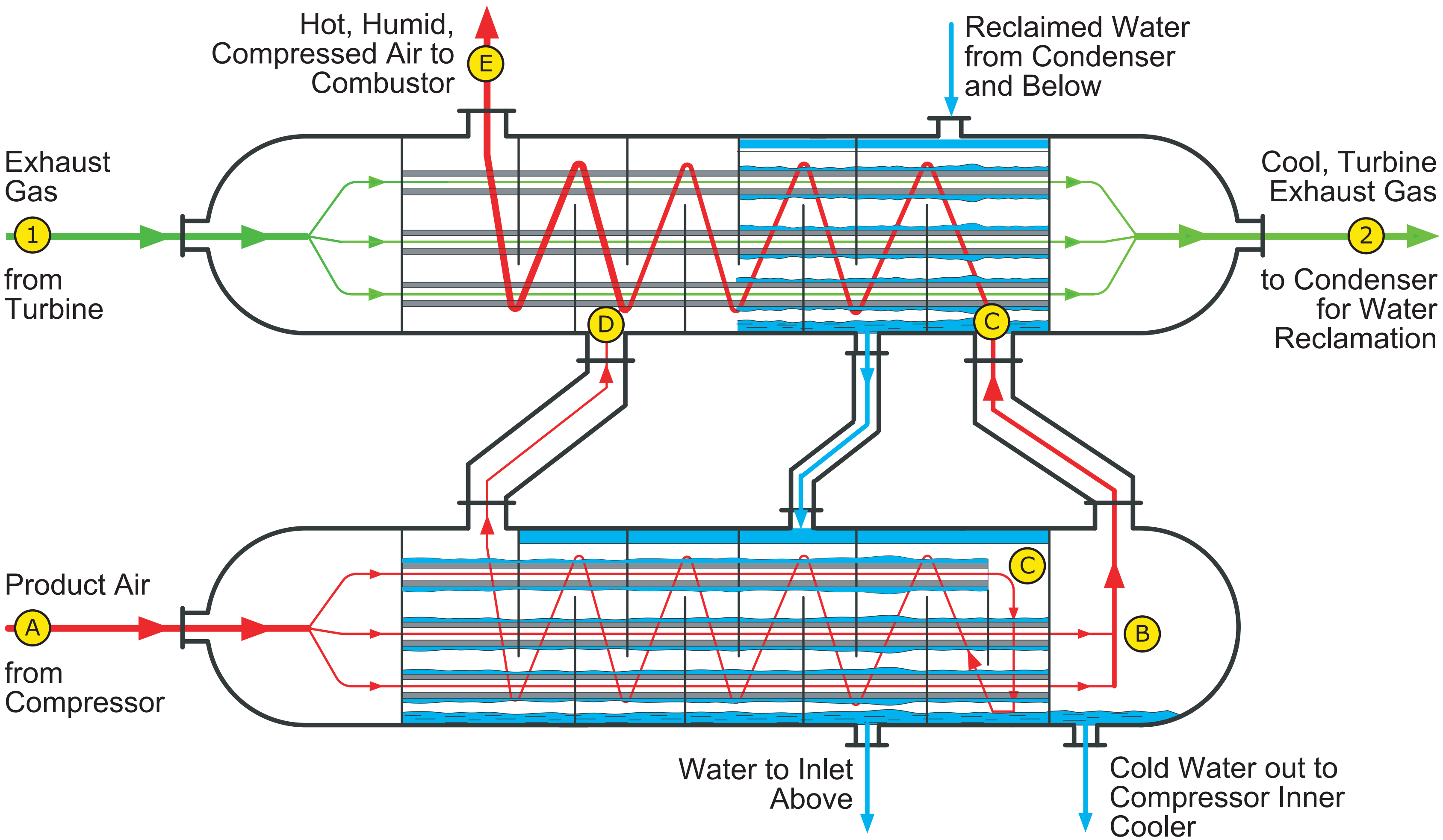
6. Diagram of a HAT cycle. Note its need for more equipment, compared with the M cycle depicted in Figure 4. *Courtesy: Idalex Inc.*



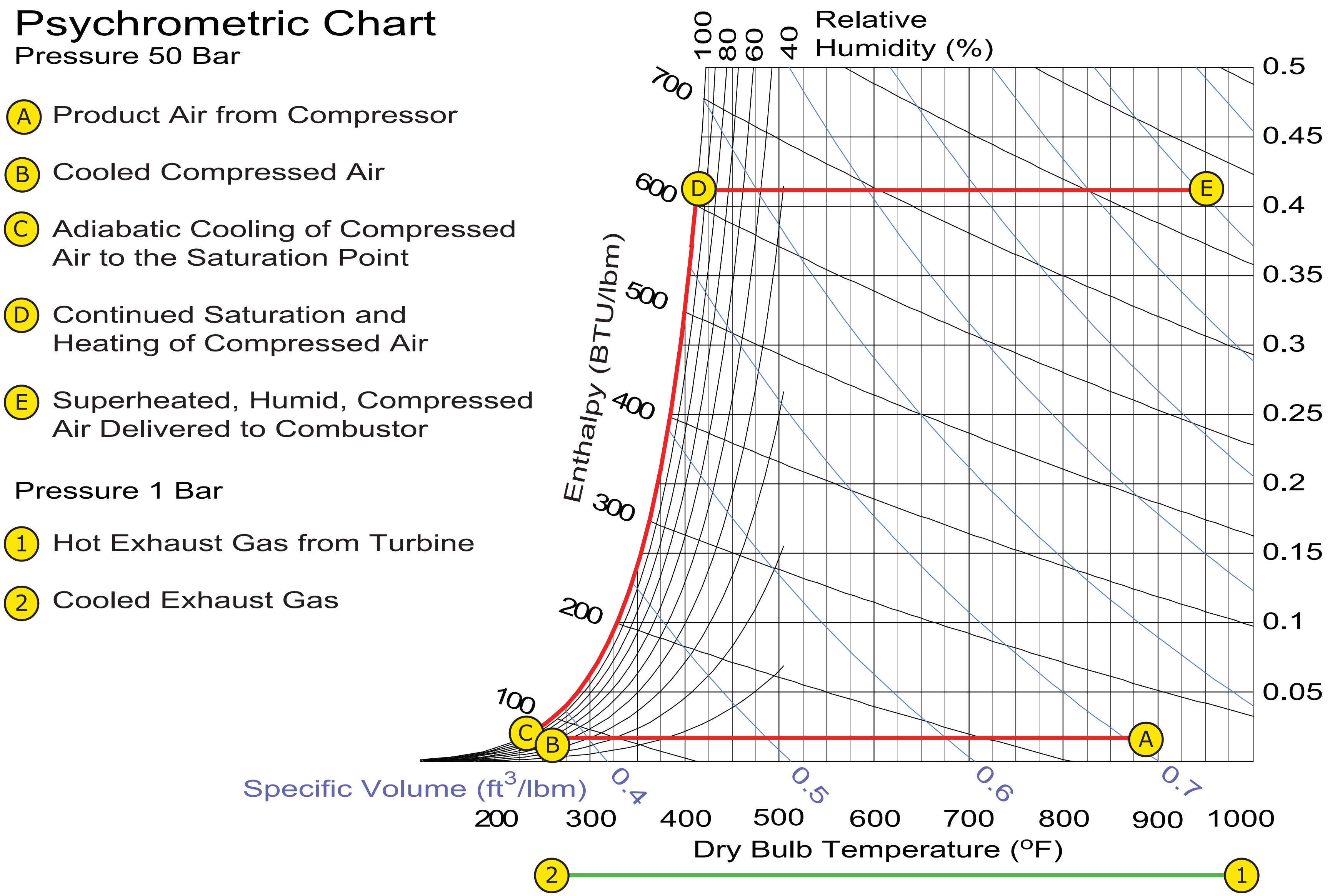
MAISOTSENKO COMBUSTION TURBINE CYCLE (MCTC)



Maisotsenko Cycle Air Saturator and Turbine Exhaust Cooler



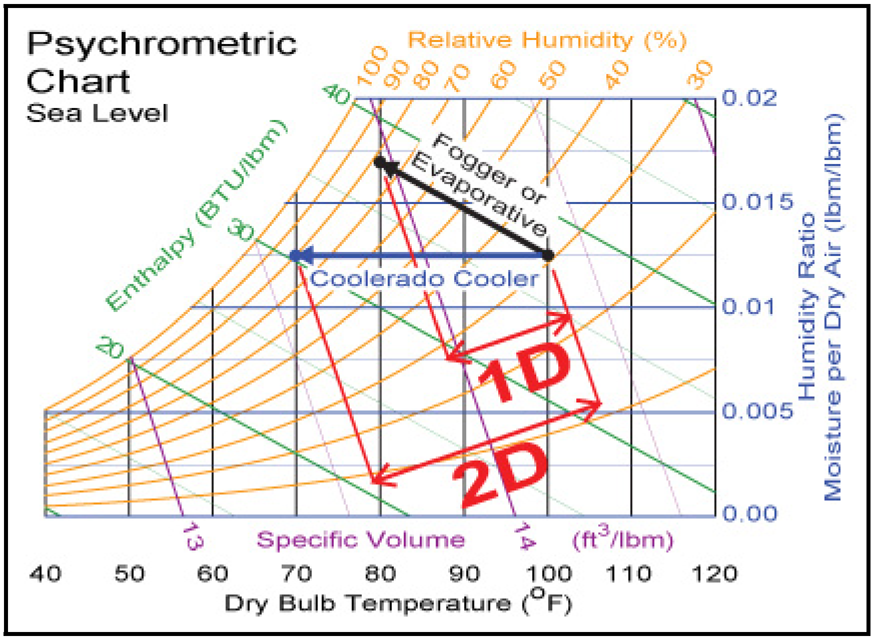
Maisotsenko Cycle Air Saturator / Super Heater



The Coolerado Cooler™ for Combustion Turbine Cycles

According to GE: "An inlet cooling system is a useful gas turbine option for applications where significant operation occurs in the warm months and where low relative humidities are common. The cooled air, being denser, gives the machine a higher mass-flow rate and pressure ratio, resulting in an increase in turbine output and efficiency. This is a cost-effective way to add machine capacity during the period when peaking power periods are usually encountered on electric utility systems." [1]

However, inlet cooling with vapor compression systems can be cost prohibitive for the amount of energy gained as compared to the power used for cooling. Also, fogging and evaporative cooling systems can introduce water into the compressor, causing blade erosion and voiding the warranty on the system.



The Coolerado Cooler offers a new and better method (refer to the psychrometric chart above). To gain maximum air density, it is best to cool the air without adding moisture. This is called sensible cooling, and it follows the horizontal constant humidity line labeled 'Coolerado Cooler.' Sensible cooling is more perpendicular to the constant volume line, resulting in a much greater increase in air density.

Adiabatic cooling is achieved by adding moisture to the air, but no work is actually done. This is why fogging and evaporative cooling follows the constant enthalpy (energy) line labeled 'Fogger or Evaporative.'

Plotting Coolerado cooling and evaporative cooling[2] on the same chart demonstrates that the Coolerado Cooler produces roughly twice the air density under these conditions.

Twice the air density represents roughly twice the power gain. Instead of a 3 to 15 percent gain in output,[3] 6 to 25 percent can be expected with a Coolerado Cooler.

There is more cooling potential if wanted. What Coolerado rejects as waste is nearly saturated air a few degrees warmer than what the evaporative or fogging system produces as product. Use this cool, moist air for the compressor inter-cooler or generator to boost efficiencies even higher.

References

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3. IBID, Figure 37