USING AIR CONDITIONING TO DEMONSTRATE 1ST AND 2ND LAW ANALYSIS

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ABSTRACT

2nd Law **analysis** techniques have the advantage of demonstrating the lost work associated with each non-ideal process in an engine or the extra work associated with each non-ideal **process** in an air conditioner, but the existing text books do not provide good examples of the applications of these techniques. Thus, a paper was presented and published for the 1995 conference to demonstrate the use of these techniques for fuel burning Carnot and **Rankine** cycles. This paper presents similar examples of the use of these techniques for air conditioning analysis.

1. Introduction

Recognizing that we live on a **finite** planet with limited fuel resources in the ground and with limited atmosphere to absorb the products of **combustion**, engineers will be continually and increasingly challenged to make our expanding modern society more energy efficient.

This means that **all** energy conversion processes and cycles should be continuously examined to establish how much fuel is being consumed and for the potential of improving efficiency with better cycles, heat exchangers and any other improved technologies.

A **firm** understanding of thermodynamics is the prerequisite for **defining** existing **efficiencies** and the opportunities and limits for such improvements. It is also noted that overall fuel consumption is typically a complicated function of many related **efficiencies**, which can be classified in various ways.

1st Law **efficiencies** can be described as the ratio of the **useful** energy achieved to the energy that must be provided. The **efficiency** of a boiler or furnace represents a 1st Law efficiency of a **process**, while the net efficiency of a power plant is the 1st Law efficiency of a cycle.

In **contrast**, 2nd Law **efficiency** is best described as the ratio of actual to ideal performance. The isentropic efficiency of a turbine, pump, or compressor is the 2nd Law efficiency of a process, while the ratio of the actual efficiency of an engine to the ideal efficiency of an engine with the same heat source and sink describes the 2nd Law **efficiency** of a cycle.

Similarly, two methods can also be defined for evaluating the overall performance of a cycle. The **first** method can be defined as a **1st Law method** because it **examines** the 1st Law energy balance for each process and for the total cycle, from which the ratio of desired energy achieved (i.e., the net work from engine) to what is supplied (i.e., the fuel) can be directly determined.

The second method requires the 2nd Law and thus is called a 2nd Law method. This method starts by determining the ideal performance of a cycle and then applies the 2nd Law to determine the irreversibilities of the individual processes. If it is an engine or power producing cycle, the **irreversibilities** represent lost work. If it is an air conditioning or refrigeration cycle, the **irreversibilities** are the extra work that must be supplied.

While both the 1st and 2nd Law methods should give the same net efficiency or performance, the 2nd Law method provides additional information since it quantifies the lost work or extra work associated with each less than ideal process. Thus, the 2nd Law technique provides better guidance in terms of which of the processes represent the largest loss, and thus the best opportunities for improving performance.

Some thermodynamic text books describe the required principles, but do not provide good numerical examples to demonstrate their application. Thus, it is the author's goal to develop and present some such examples for inclusion in future text books.

A 1995 paper by the author (Reference 1) used the familiar fuel burning **Rankine** cycle to demonstrate 1st and 2nd Law analysis. The 1st Law method presented the net plant efficiency as the product of the **boiler efficiency** and the cycle **efficiency**.

The 2nd Law method showed the same net efficiency could be calculated by defining the efficiency of the ideal fuel burning engine or Wicks cycle (Reference 2) as a function of the maximum combustion product temperature minus the seven lost efficiencies associated with the **superheating**, **boii** and water heating sections of the **boiler**, the **stack loss**, the turbine, the condenser and the pump.

While both methods showed the same net efficiency, the 2nd Law method provided additional understanding of how much is lost in each process, and thus provided some guidance for the relative effectiveness of various efficiency enhancing efforts.

For example, the 1st law method showed a 90% **boiler efficiency** that appeared to be very good, but the 2nd Law method showed that most of the lost efficiency was associated with the boiler because of the large temperature differences for the heat transfer process between the combustion products and the **Rankine** cycle working fluid. Thus, the 2nd Law **analysis** was required to fully define the limits of a **Rankine** cycle.

The 2nd Law analysis also provided a basis for understanding the **efficiency** improving potential of a combined cycle comprised of an internal combustion gas turbine topping cycle and an external combustion steam turbine bottoming cycle.

It is noted that the application of 2nd law analysis **techniques** requires obtaining the entropy of the working fluid to a high degree of **precision**, which was **difficult** to do with the tables in the back of the book, but can be done quite readily with the newly available thermal physical properties on computer disk.

This paper will describe similar but somewhat different 1st and 2nd Law methods for analyzing air conditioning with the belief that these examples should also be included in future thermodynamic text books.

2. Evaluating an Ice Air Conditioner

The first example is a **one ton** system (i.e.,

12,000 Btu/hr) in which ice is used for cooling and with the inside air temperature of 70 F and the outside air temperature of 100 F as shown in Figure 1 in which ice is supplied to the tank at 32 F and 32 F water drains from the tank. Heat at 70 F (530 R) is released by the house air and absorbed by the ice at 32 F (492 R).

Figure 1 A one ton ice air conditioner by melting one ton of ice per day which absorbs 288,000 (Btu/day).

It is noted that the amount of cooling that is provided by melting one ton or 2,000 lbs of ice per day with a heat of fusion of 144 Btu/lb corresponds to 288,000 Btu/day or 12,000 Btu/hr. It is also noted that the process between the house air and the melting ice is irreversible since heat is transferred over a 38 F temperature difference.

Thus there is a net entropy increase of 41.966 (Btu/day R) as a result of this heat transfer over a temperature difference as shown in Figure 1. The corresponding irreversibility or lost work is 23,503 (Btu/day) which is attained by the 2nd Law in the form of multiplying this entropy production by the temperature of the infinite heat reservoir which is the 100 F outside air temperature.

This suggests that there is some ideal or **reversible** method for using the resource of 1 ton of ice per day and performing the same job of removing the same 288,000 (Btu/day) of heat from the house such that an extra work will result from this ideal technique that is equal to the lost work by the **non-ideal** method.

Such an ideal system is shown in **Figure 2**. It **consists** of operating a reversible Carnot cycle engine using the outside air as a heat source and a ton of ice per &y at 32 F (492 R) for the cold reservoir, and a Carnot heat pump to remove 288,000 (Btu/day) from the house and transfer it to the outside air. This **Carnot** engine will produce 39,805 (Btu/day) of work and the **Carnot** air conditioner will consume only 16,302 (Btu/day) of work, which yields an extra work of 23,503 (Btu/day) which is the amount of lost work found in Figure 1 for the non-ideal technique.

Figure 2 A reversible method for utilizing one ton of ice per day while providing 1 ton= 288,000 (Btu/day) of heat removal from the building.

3. Evaluating an Electric Compression Air Conditioner

We now extend these 1st and 2nd Law techniques to the evaluation of cooling the same house with the same inside and outside air temperatures by means of a one ton or 288,000 (Btu/day) electric compression air conditioner shown in **Figure 3**.

Figure 3 A one ton electric compression air conditioner.

The condensing unit is defined in terms of the **desuperheating** section and the **condensing section**, with the condensing occurring at 140 F which is 40 F higher than the outside air temperature. The compressor has a 70% **isentropic efficiency** and an adiabatic throttle reduces the saturated high pressure liquid from the condenser to a mixture to the evaporator.

It is noted that there are five irreversible processes associated with this air conditioner corresponding to the compressor, the **desuperheater**, the **condenser**, the **throttle** and **evaporator**. A **property** table and 1st Law process and cycle table is developed to determine the power requirement.

We assume the working fluid is Freon 22 and obtain the properties at each defined point in the **process**. These properties are **first** obtained from the **pressure vs enthalpy** chart in Figure 4 and then from the computer based data for more **precision** and summarized in Table 1.

Table I

1	69.6	30	490	.78210	107.28	100	.2218
2	3s1.9	188	648	.178s1	12s.03	-	.2218
2	3s1.9	221	681	.19808	132.64	-	.2333
a	3S1.9	140	600	.14418	112.93	100	.2023
3	3S1.9	140	600	.01552	S2.53	O	.10163
4	69.6	30	490	30690	52.53	38	.10997

Table II
1st Law Process • nd Cycle Table for Corresponding
One Ton Electric Compression Air Conditioner
(Note $\dot{m} = \$260.27 \text{ (lb/day)}$)

Process	$\dot{Q}$ (Btu/day)	$\dot{m}^*(\text{hout-hin})$ (Btu/day)	W (Btu/day)
1-2 Compressor	0	+ 133,384	-133,384
2-3 Desuperheater	-103,664	-103,384	0
3-4 Condenser	-317,720	-317,720	0
4-1 Throttle	0	0	0
4-1 Evaporator	+ 288,000	+ 288,000	
Net for Cycle	-133,384	0	-133,384

Each of the five non-ideal processes will be characterized as a producer of entropy. The evaporator, desuperheater and condenser produce entropy because of heat transfer over a temperature difference. The compressor and throttle valve are adiabatic, but produce entropy because of internal friction, and thus their entropy production is the Freon flow rate times the entropy increase from inlet to outlet.

The entropy production for each process is now calculated and then multiplied by the outside temperature to obtain the extra work associated with each process and for the total cycle and these results are summarized in Table III which shows a net extra work of 117,802 (Btu/day).

The Carnot work plus the extra work becomes 133,384 (Btu/day) from Table III should and does corresponds to the X33,384 (Btu/day) compressor work from the 1st Law method as was shown in Table II.

Table III

2nd Law process and Cycle Table to Summarize Entropy Production Rate and Irreversibility(= Extra Work) Rate

Process	$\dot{\text{del}} \dot{S}$ (Btu/day)	Extra Work = $T_{in} \dot{\text{del}} \dot{S}$ (Btu/dayR)
1-2 Compressor	60.493	33,876
2-3 Desuperheater	22.046	12,346
3-4 Condenser	37.806	21,171
4-1 Throttle	43.870	24,867
4 - 1 Evaporator	44.860	25,122
Net for Cycle	209.075	117,082

$$\text{Watt} = \dot{W}_{\text{ideal}} (= 16,302) + \dot{W}_{\text{extra}} (= 117,082) \\ = 133,384 \text{ (Btu/day)}$$

Notes:

1. $\dot{W}_{\text{ideal}}$ is the Carnot AC work in Figure 2.
2. The $\dot{W}_{\text{net}}$ from the 1st Law method as shown in Table II is the same as $\dot{W}_{\text{net}}$ from the 2nd Law method which is the sum of the for Carnot Cycle $\dot{W}_{\text{ideal}}$ from Figure 2 and $\dot{W}_{\text{extra}}$ from Table III.

4. Discussion

The author believes that the analysis of these two air conditioning systems by two different methods and obtaining the same results provides another profound and important demonstration of 1st and 2nd Law performance analysis techniques.

This belief has been confirmed by the students who have performed this type of analysis as homework assignments, in which they have also used other refrigerants which will have different property values, but still yield the same power requirement result.

While the 1st and 2nd Law methods both yield the same result, the 2nd Law method provides additional information of how much extra work is associated with each process, and this provides the additional guidance in how best to improve performance.

Thus, the students can evaluate the relative benefits of enhanced heat transfer by more area or other techniques in the evaporator or condenser, a more efficient compressor, or possibly replacing the throttle valve with a power work producing expander.

Acknowledgement:

The author thanks the Niagara Mohawk Power Corporation for the energy related projects grant that helped make this work possible.

References:

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Professor Frank Wicks received • BMarineE from SUNY Maritime in 1961, • MSEE from Union College in 1966 and a PhD in Nuclear Engineering from RPI in 1976. He was Commissioned in the Navy and served as a shipboard engineering officer, and then as a General Electric aircraft engine, turbine, nuclear and electric utility systems engineer. He was Supervisor of the RPI Nuclear Reactor and Operations and has served at Union College since 1988. Dr Wicks is • Professional Engineer and a member of AAAS, AIAA, ANS, ASCE, ASEE, ASME, IEEE, Sigma Xi, Pi Tau Sigma, and Tau Beta Pi and holds several energy conversion and conservation related patents. He is also a licensed pilot for engine powered aircraft and gliders.