"WHAT IS AN ENERGY BALANCE AND WHY SHOULD I CARE?"

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Juan Parra / Andrew Fiala
Project Professional / Sr. Project Professional
SCS Tracer Environmental
6470 Kahuna Rd # B
Kapaa, HI 96747
Tel: 561 866-6157
Email: jparra@scsengineers.com
Fax: 760 744-8616

All refrigeration systems begin and end with a material and energy balance. What is refrigeration as we know it? Refrigeration is the process or ability to grab the heat from a specific matter, material or place, remove it and reject it somewhere else. This process is typically associated with lowering the temperature of the matter or material. Heat will always travel from a higher temperature to a lower temperature.

This paper will focus on the true definition of heat, the importance of an energy balance, how to calculate an energy balance, and the issues maintenance personnel face every day trying to ensure heat is removed and product stays cool.

Heat is a form of energy. There are 2 types of heat:

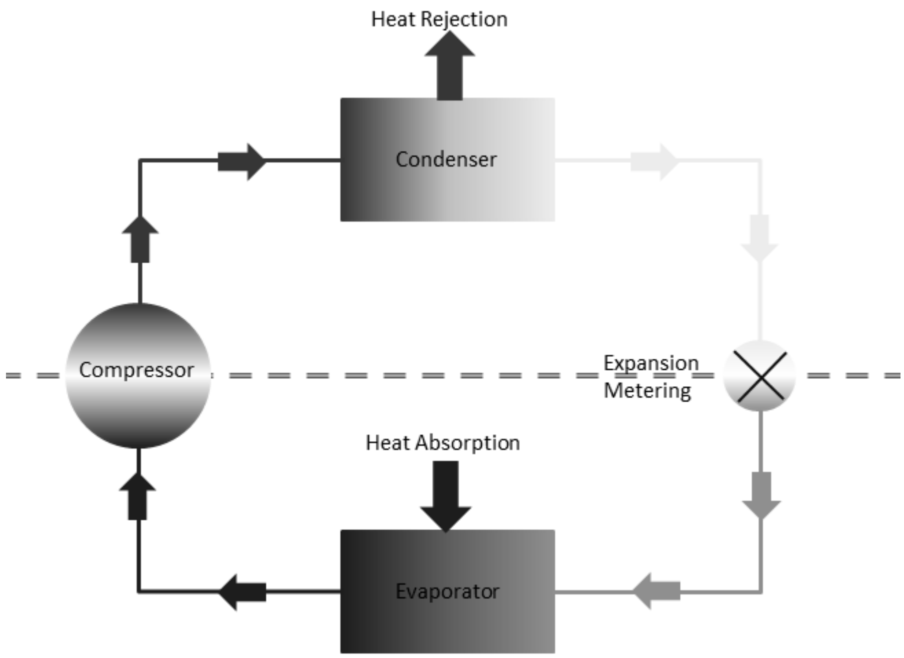
- Sensible heat which cause a change in temperature ($Qs = M\ x\ Cp\ x\ \Delta T$).
    - Qs is sensible heat
    - M is the weight of the substance
    - Cp is the specific heat of the substance
    - ΔT is temperature differential
- Latent heat which will cause a change in phase ($Ql = M\ x\ hl$)
    - Ql is latent heat
    - M is the weight of the substance
    - hl is the latent heat content

Total Heat will be the sum of both sensible and latent heat ($Q = Qs + Ql$). Heat can be measures in BTUs.

Why is energy balance important in refrigeration?

In order to answer this question, first it is necessary to understand the basic refrigeration cycle. Any and all refrigeration systems have the following 4 main components: evaporator compressor, condenser and expansion valve/metering device (Figure 1)

Figure 1: Basic Refrigeration Cycle



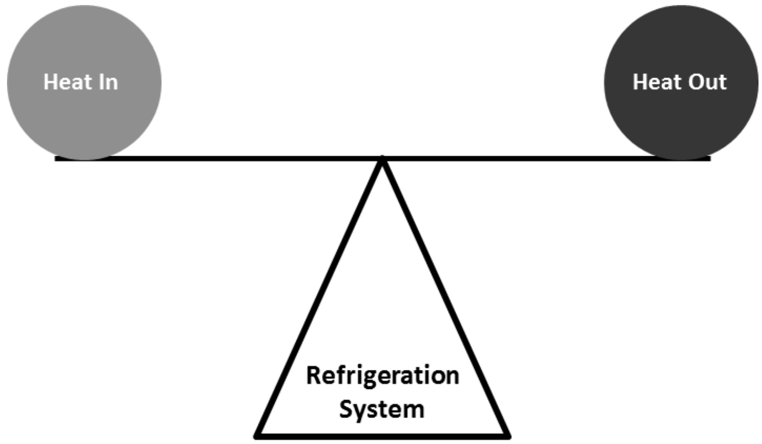
Source: Prepared by SCS Engineers.

Each component has a specific function:

- The Evaporator allows heat from the desired area, product, matter, etc. to be absorbed and transferred to the refrigerant forcing it to change phase from liquid to vapor.
- The Compressor will increase the refrigerant pressure/temperature.
- The Condenser allows heat from the refrigerant to be rejected to the atmosphere, forcing the refrigerant to change phase from vapor to liquid.
- The Expansion or Metering Device allows for a pressure/temperature drop of the liquid refrigerant.

The First Law of thermodynamics states that energy cannot be created or destroyed, it can only be transformed. A refrigeration system transforms energy by moving heat from an undesired place to a desired placed. In order to do so efficiently a balance between all system components is necessary to ensure the desired amount of heat can be moved. There has to be an energy balance (Figure 2).

Figure 2: Refrigeration System Energy Balance

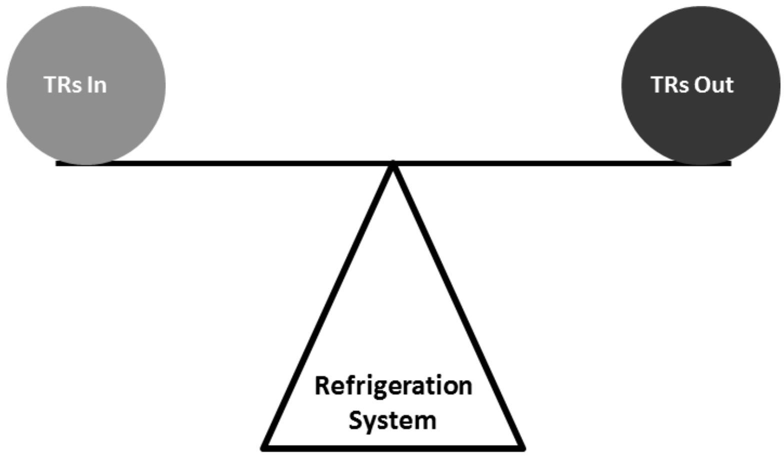


Source: Prepared by SCS Engineers.

In the United States refrigeration industry it is common to use the term "Ton of Refrigeration" (TR), which is a unit representing the rate of heat removal or heat removal capacity. Another common unit is the BTU/h, 1 TR = 12,000 BTU/h.

Analyzing figure 2 it can be said that in order to have an efficient refrigeration system, the amount of tons of refrigeration coming in to the system has to be balanced with the amount of tons of refrigeration being rejected by the system. In other words the rate of heat being removed from an area or product by our refrigeration system (heat coming in to the system) has to be balanced with the rate of heat being rejected to atmosphere (heat leaving the system) (Figure 3).

Figure 3 TRs In / TRs Out



Source: Prepared by SCS Engineers.

Equipment in the refrigeration industry has a rating of their ability to move heat from/to the ammonia or refrigerant. This rating is usually established by the OEM and it's usually expressed in TR or BTUs in the United States. Additionally the rating for specific pieces of equipment will vary depending on systems operation. Systems will typically be designed considering geographical location including weather patterns, desired area / product temperature, type of operation, amount of people, additional heat loads like lighting, among other things. What this means, is that the OEM established rating may vary depending on whether the system is being used as it was designed or if it has been tweaked to meet specific needs. At the end of the day, the system will need to be balanced for proper operation. **For this paper it will be assume that equipment will be used in designed conditions. However keep in mind that equipment ratings are associated with product, air, refrigerant temperature differentials, etc. The greater the temperature differential is the larger the amount of heat associated will be.**

Let's look at a simple energy balance on a single stage system.

It can start by adding all the loads from evaporators, heat exchangers etc. this will provide the total TRs that will need to be handled by the compressors (Table 1).

Table 1 High Stage Loads. Example.

ID #	Description	Manufacturer	Model #	Serial #	Tonnage (TR)	Suction Temp.	Comments
T1	TANK	-	NA	NA	4.5	24F	
T2	TANK	-	NA	NA	6	24F	6TD / 60,000GAL
EV1	EVAPORATOR	KRACK	NA	NA	5.6		DX
EV2	EVAPORATOR	EVAPCO	NA	NA	47.9		DX
EV3	EVAPORATOR	EVAPCO	NA	NA	47.9		DX
EV4	EVAPORATOR	KRACK	NA	NA	9.9		DX
EV5	EVAPORATOR	EVAPCO	NA	NA	9.9		DX
HX1	PLATE AND FRAME	ALPHA-LAVAL	NA	NA	251	26F	
HX2	PLATE AND FRAME	FES/APV	NA	NA	120		
HX3	TUBE-IN-TUBE	FELDMEIER	NA	NA	75		

TOTAL HIGH STAGE LOADS:	577.7

Source: Prepared by SCS Engineers.

In order to determine if the compressors are capable of handling the design loads its needed to add the compressors TR capacities (Table 2)..

Table 2 High Stage Compressor Capacity. Example.

Machine ID#	Type	Model	Serial #	Tonnage	HP	Operating Temp	Comments
C1	Screw	RWB-II134	NA	271	300		
C2	Reciprocating	448B	NA	112.8	150		
C3	Screw	RWB-II134	NA	271	300		
C4	Screw	RWB-II100	NA	203	250		

TOTAL COMPRESSOR CAPACITY:	857.8
TOTAL MOTOR HP:	1000

Source: Prepared by SCS Engineers.

Comparing Table 1 and Table 2, compressors are capable of handling all the high stage loads (Table 3).

Table 3 High Stage Loads vs Compressor Capacity.

High Stage Loads	577.7 Tons
High Stage Compressor Capacity	857.8 Tons
Balance	280.1 Tons

Source: Prepared by SCS Engineers.

Condensers capacity needs to be assessed (Table 4) and compared to our compressor capacity from Table 2 (Table 5). It is important to keep in mind that condensers need to be capable of handling additional heat of compression that is inflicted to the refrigerant by the compressors (Heat of Rejection).

Table 4 Condenser Capacity. Example.

Condenser ID #	Description	Model #	Serial #	Discharge/TR @ 96F	Discharge/TR @ 68F	Sump Design	Comments
EC-1	EVAPCO	PMCB-XXXX	NA	709			
EC-2	EVAPCO	ATCE-XXXX	996205M-3M	180			
EC-3	BAC	VXMC-NXXX	NA	187.9			
			TOTAL CONDENSER CAPACITY:	1076.9			

Source: Prepared by SCS Engineers.

Table 5 Ammonia Refrigeration System Energy Balance. Example.

High Stage Compressor Capacity	857.8 Tons
Heat of Rejection (HP X 2545)/12000	212.1 Tons
Total High Stage Load Capacity	1069.9 Tons
Condenser Capacity	1076.9 Tons
Balance	7.0 Tons

Source: Prepared by SCS Engineers.

From Table 5 it is determined that the system is balanced. This means that the compressors are capable of handling the TRs coming from the evaporators, heat exchangers, among others. Also the condensers will be able to handle the TRs coming from the compressors at full load.

Analyzing Table 1 and table 2, it seems that one of the 300 HP compressors does not need to operate in order to handle the high stage loads. Let's assume that this is a backup compressor for high demand circumstances such as bringing a room from ambient temperature to a desired lower temperature, or maintenance needs, etc.

Who Left The Door Open and Why Does Maintenance Care?

In order to answer this question lets imagine a freezer room that is maintained at 0°F, outside of the room is a loading dock maintained at 40°F with 3 doors connecting the room with a dock to allow for product flow.

If each door opening is approximately 8 ft x 12 ft, a single door remaining open for 30 minutes can represent approximately 10 TR [1] of additional heat load that will need to be removed by the refrigeration system. Comparing to our analysis of Table 1 and Table 2, this alone can force the backup compressor to start running.

A typical screw compressor without a VFD running 20% loaded will still consume 52 % of power as if it was loaded at 100% [2]. For the purpose of this paper motor efficiency will be assumed as 1.

$$Additional\ Cost = 300\ HP\ x\ 0.745\ \frac{kW}{HP} x\ 52\%\ \ x\ Run\ Hours\ x\ Energy\ Cost$$

If a single door was left open for a month this could represent

$$Additional\ Cost = 300\ HP\ x\ 0.745\ \frac{kW}{HP} x\ 52\%\ \ x\ 720\ hours\ x\ 0.1 \frac{\$}{kWh}$$

$$Additional\ Cost = \$8{,}379$$

Finding open freezer doors is not uncommon; there are many circumstances that frequently take precedent over repairing a door in a timely manner. Here are a few common ones.

- Operator culture.
- Meeting monthly financial goals.
- Difficulty finding parts.
- Damages beyond repairs.

It is important to keep in mind that this logic can be applied to just about every part of the refrigeration system. Examples include:

- Scaled condenser will not allow removing heat efficiently forcing a higher head pressure. Condenser heat exchange surfaces should be examined to verify the heat transfer surface is clean of build-up and the water distribution is effective at covering the coils. In RETA's Industrial Refrigeration Book 1 it is stated that as little as 1/32 in of scale on a condenser coil can reduce the capacity by as much as 30%[3]. A reduction in condenser capacity will lead to higher discharge pressures and, therefore, higher compressor horsepower being required. Non-condensable gasses in the system can also cause higher discharge pressures and must be removed. Studies have shown that decreasing condensing pressure, hence condensing temperature, can generate 1.5% compressor savings per °F [4].
- Burnt evaporator motors and, dirty evaporator coils or dirty heat exchanger surfaces will ultimately reduce the overall efficiency of the system. Many times the loss of efficiency in evaporators is counteracted by lowering suction pressure in the engine room. Studies have shown that increasing suction pressure, therefore, suction temperature can generate 2% compressor savings per °F [4].

Most compressor manufacturers use 31.5 psig suction pressure and 151 or 181 psig discharge pressures to produce the high side compressor tonnage rating. In our example, let's assume that our system runs at a suction pressure of 30 psig (17 °F) and discharge pressure of 184 psig (96 °F). If by doing proper and timely maintenance to our evaporators (clean heat exchange surfaces, fans/pumps running properly, etc.) and our condensers (water treatment to prevent / remove excess scaling, clean spray nozzles providing proper water distribution, fans running properly, etc.), suction pressure is increased to 31.5 psig (18 °F) and discharge pressure is decreased to 181 psig (95 °F) this could represent 3.5% of compressor savings.

Looking at our example above where 3 out of 4 compressors are normally running, this could represent up to the following savings per month.

$$Savings = 700\ HP\ x\ 0.745\ \frac{kW}{HP} x\ 3.5\%\ \ x\ Run\ Hours\ x\ Energy\ Cost$$

$$Savings = 700\ HP\ x\ 0.745\ \frac{kW}{HP} x\ 3.5\%\ \ x\ 720\ hours\ x\ 0.1 \frac{\$}{kWh}$$

$$Savings\ = \$1{,}314$$

Sometimes the effect is not direct on the refrigeration system but on the product itself. Entire batches of product can be damaged; production needs may not be met, among others. On occasions, something as simple as leaving a door open can throw the facility energy balance off and force a system to shut down.

Analyzing this simple example it becomes apparent the importance of having a clear understanding of our systems actual performance. An energy balance is a very useful tool to do so. PSM regulations require that facilities have this in their PSM program. As it has been shown, there is real life value in understanding our systems capacities, operation and efficiency that can be translated to substantial dollar savings on a yearly basis. Savings can be re invested in the facility. It can also be a tool in order to get necessary funds for maintenance needs or to avoid trying to save money by postponing timely repairs. Calculating the total consequence of an unbalance system is somewhat more complex but there are big money savings to be made from running a properly energy balanced refrigeration system.

References:

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[2] Cascade Energy, Inc. 2010. "Chapter 4. Best Practices for Equipment, Systems and Controls". *Industrial Refrigeration Best Practice Guide*. Third Edition. USA, pp 62.

[3] RETA. 2010 "Chapter 9. Condensers and High Pressure Receivers". Industrial refrigeration Book 1. Revision 11/27/2010. USA. pp 9-22

[4] Cascade Energy, Inc. 2010. "Chapter 4. Best Practices for Equipment, Systems and Controls". *Industrial Refrigeration Best Practice Guide*. Third Edition. USA, pp 49,52.