Bloom’s Taxonomy Levels as applied to developing Energy Efficient Air Conditioner Compressor

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ABSTRACT

The education system, especially in Engineering and Technology is to be built in a systematic method to bring out new innovative products, processes and services. Bloom’s Taxonomy of 6 levels of teaching, evaluation and learning has been thoroughly analyzed and accepted all over the world. Today the accreditation bodies also look for this or similar methods of cognitive education system in institutes and universities which offer higher level professional courses. In this report an air conditioner compressor development was required to be designed to adhere to the new laws of global climate conditions and energy requirements. The steps of development during the year 2001 was summarized and listed under the categories of Bloom’s Taxonomy levels which are presently used in education. The objective was to show the benefit for students to continue their Learning process and implement in their career to get quick and consistent results. The study is the process adopted in developing a new reciprocating compressor taking competition, Ozone depletion, Global Warming Potential and the Energy rating into consideration.

Keywords: Bloom’s Taxonomy, Refrigeration & Air Conditioner, Compressor Design, Ozone depletion, Refrigerants, Energy efficiency.

1. INTRODUCTION

The learning teaching Pedagogy in any institute specifically in Engineering Institutes is focused on providing relevant knowledge so that at the end of the learning the student may improve product/ process / services by creation or developing new innovations. When a structured way of implementation is adopted it would lead to more consistent outcomes Benjnim Bloom [1], [2], [3] defined these hierarchical steps of : Remember, Understand, Apply, Analyze, Evaluate, Create; which are presently called by Digital Bloom’s Criteria of learning stages or cognitive levels. The original taxonomy level has Synthesize instead of create but the presently used levels are universally accepted and used in accredited system of education. The students are told beforehand that they are expected to learn the subject to fulfill the course objectives and obtain the course outcomes at the end with defined attainments for each level as designed by the course instructor and approved by the department academic comities and institute or University Boards of Education Studies. Figure 1. Shows the present used levels of organized steps called Taxonomy. At Institute level the course in charge frames appropriate Qs in the assignments, exams to test the level of student’s learning he uses appropriate verbs like : Recall, define, list state to test how much student remembers; Uses verbs such as explain, classify, describe to test the understanding level of the student of the concepts taught; He might test how well he can apply the formula learnt by asking him to apply for a specific problem or ask him to evaluate a set of values doing an experiment; Analyze is the process of keeping output results in a systematic way by drawing graphs and tables to show the relationships that exist; Evaluation is the area where from the analysis proper inferences are made to make a decision like if mass of an object increases for the same acceleration the force increases
proportionally; Finally, when the objective is not met in obtaining the desired results of product/process or service performance a new one is to be created by remembering, understanding and applying with variations and tested by analysis and evaluated for confirmation of attainment of results. This method was used extensively [4], [5], [6] in establishing educational structures for cognitive learning by different educational and process organizations.

Figure 1. Bloom’s Taxonomy Levels [1]

In the present report the it is shown that the Bloom’s taxonomy levels can be applied in the work he does in the industry. Many a time he starts by remembering the basics he learnt in college and adds understanding the specific industry standards, competition and sets benchmarks to be attained as goals. Also, they would be required to obtain new understanding of textured documents, data, reports articles specific to their area and remember and apply accordingly. As they take up more challenging jobs of quality, performance, productivity, continuous analysis will be required to evaluate their position with respect to competition. In today’s competitive business there is a continuous improvement required by a team work of managers, engineers and workers, different work groups work relentlessly to retain and peak their position among various world class peers. This approach is required to evaluate and reposition with creating new products.

Application of the Bloom’s taxonomy levels is relevant in industry too. A study of EER improvement of this approach from Tecumseh Products Ltd, Hyderabad India does continuous improvement of products [7] and also adopts to change the products with Ozone acceptable greenhouse acceptable refrigerant R134a compressors [8]. A good test room to evaluate the performance of competitive models to provide better compressors. A good psychrometric test room is required to test Refrigerators, Water coolers, Air conditioners as per Bureau of Indian Standards, BIS norms [9]. Setting up a good test room with accurate calibrated instruments with international standards. Compressors for air conditioners were developed and summarized in this report with a hierarchical Bloom’s Taxonomy levels process. This study was at Tecumseh Research and Development (R & D) in 1999 -2004 to initiate alternate refrigerants for air conditioners to replace the R22 as per Montreal Protocol of 1987.

2. KNOWLEDGE

2.1 Market competition: Understand

The first two steps of remember & understand are the basic requirements specific to the area of work there are compressors for different applications shown in Figure 2. Our interest is to develop reciprocating compressors for room air conditioning applications and compete with more efficient rotary compressors. It is important to identify the advantages of reciprocating over rotary compressors and take advantage in the design.
It is known that reciprocating compressors are low back pressure compressors, that is the shell has lower temperature, lower pressure, lower noise and vibrations compared to the high pressure rotary compressor. Specially, in tropical and high ambient Middle East market there is advantage with low back pressure reciprocating compressor. The objective was to exploit these aspects and make suitable special market oriented compressors.

2.2 Thermodynamic Basics: Remember
To make basic calculations it is important to recall, define and list all the equations and calculate basics say from 2nd Law of thermodynamics which defines that work is to be done which is the electric power, $W_r$, input to the compressor to remove heat from low temperature, $T_r$, to high temperature outside temperature $T_2$ as shown in Figure 3. From this law we can calculate Capacity, $Q$, Power of Compressor, $W_r$ and COP or EER of the compressor or appliance, $Q/W_r$.

2.3 Ozone depletion: Understand
In 1987 at Montreal a protocol, an industry and government and climate specialists agreed norms were adopted to phase out Ozone depleting refrigerants in a phased manner. In Figure 4. It is observed that compared to 1987 in 1997 there is a violet patch showing reduction in ozone above the northern pole regions in the stratosphere about 15 to 30 Kilometers above the earth due to photo sensitive chemical reactions. Bromine and Chlorine followed by Fluorine are the most harmful which react with Ozone, O3 and convert to Oxygen, O2. This is a chain reaction as at the end the Cl or Br or Fl is retrieved back and the reaction lasts for about 20 to 25 years depleting the Ozone layer.

2.4 Global Warming: Understand
Earth provides life as it is protected by different temperature and pressure layers of gases up to about 500 kilometers above earth. The outermost layer is exosphere followed by thermosphere, mesosphere, stratosphere the one nearest to earth is the troposphere which gives us the greenhouse effect or retains the heat required for earth within its enclosure. This layer has gases like CO$_2$, N, O$_2$, Nitrous and sulfur oxides, Methane etc. Troposphere allows the high frequency waves from Sun but trap the low frequency infrared rays coming from the earth. Thus, troposphere allows the low wavelength 0-400 nm ultra violet and visual light, 400 – 700 nm come from the Sun through the various atmospheric layers of gases. Then Earth absorbs these high frequency radiation energy and gives low frequency
Infrared rays, the green house gases in the troposphere do not allow these radiations to leave and trap them to give the required heat for survival of life on earth, refer Figure 5.

However, excess heat on earth can cause warming of earth rising of ocean levels submerging land and excess heat for death of plants, animals and extinct life. In Kyoto agreement nations agreed to control carbon emission which reflects the green house effect. This has an effect on refrigerant gases. Carbon dioxide, CO\(_2\), has a Global Warming Potential, GWP, of 1 and is acceptable and used as reference. The lower the potential better. The GWP of other gases is mentioned with respect to that of CO\(_2\). In Table 2.5 it is seen R22 has a GWP of 1700 and R134a 1300, hence R134a is a better gas for climate control.

![Figure 5. Radiation form Sun and Earth](image)

**2.5 BEE Star rating of appliances:**

**Understand**

Bureau of Indian standards had meetings with Industry to bring about continuous improvements in power consumption of appliances and bring about star rating and implement through Bureau of Energy Efficiency based on the EER of the compressor and COP of the appliance. Energy Efficiency Ratio EER is in BTU/WHR the ratio of capacity of the air conditioner, in Btu/Hr, to the power in Watts it consumes. Coefficient of Performance, COP is the same ratio generally estimated of an air conditioner when both capacity and power are expressed in Watts, W. The development of compressors started at 8.0 EER

\[
8.0 \text{ EER} = 2.3447 \text{ COP}
\]

The first level development gave 9.8 EER

First level of improvements raised EER to 9.8.

\[
9.8 \text{ EER} = 2.8722 \text{ COP}
\]

Further fine tuning of parts and processes using Taguchi methods gave 10.2 EER.

\[
10.236 \text{ EER} = 3.0 \text{ COP}
\]

**2.6 Apply**

There were four challenges to be met in developing new development model for a 15Ton (18000Btu/Hr) compressor.

1. Meet global competition including Rotary compressors in terms of power, EER, Noise size and cost.

2. Develop for Acceptable replacement refrigerants R134a was selected to overcome Ozone depletion and GWP levels.

3. Have High EER & COP to meet BEE star rating, develop global standards calorimeters and Psychrometric test rooms

Chloro -Floro Carbons in Refrigerants used in R&AC appliances where identified as the main culprits for this depletion and R12, used in refrigerator industry was phased out first with R134a as a replacement. Hydrocarbons with acceptable Ozone and GDP levels at low cost have the danger of safety as they have fire hazard and they have limited applicants. The challenges of refrigerants which meeting Ozone depletion, Global warming were evaluated and among the possible alternate refrigerants R134a was selected to develop the new model of air conditioner compressors. These compressors have to be globally competitive with the rotary compressors and meet the new BEE star rating to get best efficiency compressor. Compressor is the heart of the R&AC appliances and most important part to decide the cost & performance of the appliance.

The developed compressors are tested on calorimeter to evaluate the compressor performance of power EER and shell temperatures. Compressors were evaluated in psychrometric room testing the appliance Performance and COP refer Figure 5. The state point of the air entering the evaporator and leaving the evaporator is obtained by the dry bulb and wet bulb temperatures. Corresponding
specific enthalpy is obtained and multiplying with the mass flow as measured by a flow meter will give total capacity, Q.

The electric power is measured of compressors and fan motors, W.

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EER = \frac{\text{Capacity (BTU/h)}}{\text{Power (W)}}
\]

From the Psychrometric calculations we get both cooling capacity and power of compressor +fan motors of the appliance in Watts to calculate COP.

\[
\text{COP} = \frac{\text{Capacity (W)}}{\text{Power (W)}}
\]

Another important parameter of the compressor and appliance is noise and vibrations these are evaluated in sound lab and in Anechoic rooms. These values are compared with bench mark values, customer requirements and our own set specifications for validity of the design. If any shortfall occurs from required values the next level of improvement is conducted.

Parametric studies using OA experimentation both offline and online are used for these design improvement models.

2.8 Evaluating

The requirements of Ozone Depletion of Montreal Protocol, the Green house Potential of the refrigerants are important social and climate requirements which are mandatory to be fulfilled. The protocol held in Montreal in 1987 in Montreal Canada had given deadlines for stoppage of use of different refrigerants. First R12 the age old Refrigerant used in deep freezers & refrigerators called Low back pressure applications was stopped. R134a was identified as a suitable alternative extensively tested and made available in required quantities at reasonable price. The refrigerant is supported by the Poly –ol – Ester synthetic Oil, POE, to avoid wax formation which will happen with the mineral oils which were used till then with R12 refrigerant. For air conditioning application R22 was the most used refrigerant and Among the many options available at that time R134a was selected for the development with alternate refrigerant comparison of the two refrigerants is given in Table1. R134a, Tetrafloro Ethane C2H2F4 has ODP =0 and GWP = 1300.

Table 2.5 Air Conditioning Refrigerants

<table>
<thead>
<tr>
<th>Type</th>
<th>ASH RAE No</th>
<th>Chemical Name</th>
<th>Molecular Formula</th>
<th>OD P</th>
<th>GW P</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC</td>
<td>R22</td>
<td>Chlorodifloro Methane</td>
<td>C2H2F2Cl</td>
<td>0.0</td>
<td>170</td>
</tr>
<tr>
<td>HFC</td>
<td>R134a</td>
<td>Tetrafloro Ethane</td>
<td>C2H2F4</td>
<td>0.0</td>
<td>130</td>
</tr>
</tbody>
</table>

The following comparison of the two refrigerants can be made:

1. Freezing temperature of refrigerant is lower the better as clogging in capillary can be avoided. For R22 it is -41OC and for R134a it is -26.13OC. R22 has advantage.

2. Evaporator pressure Higher the better , to lower pressure ratio. For evap. Temp -15OC, for R22 it is 2.96 Bar and for R134a it is 1.64 Bar. R22 has advantage.

3. Condenser pressure is lower the better, for operating temperature of 30OC for safe, economical tube designs: R22 it is 12.0 Bar and for R134a it is 7.7 Bar. R134a has advantage.

4. The Condenser to evaporator pressure ratio indicates the work done and is lower the better: for R22 it is 4.0 and for R134a it is 6.72. R22 has advantage.
5. Critical temperature to be high and pressure is to be low as we would like to operate condensing temperature at high ambient with good latent heat: For R22 it is 960C at 49 Bar and for 134a it is 133 at 73.8 Bar. Both have some compromising equality.

6. COP is higher the better, power/TR lower the better for -150C evaporation and 300C condensation, Carnot cycle COP is 5.74. For R22 4.66 COP and .753KW/TR.

7. For R134a 4.61 COP and .761KW/TR. R22 is marginally better but both are equivalent.

8. Latent heat per Kg is higher the better both at evaporator & condensation as it means lower mass flow rate makes lower volume of compressor and lower system sizing.

9. Specific volume of evaporation is lower the better.

10. Not flammable not explosive Halogens are acceptable Hydrocarbons are not.

11. Miscibility with oil Mineral or synthetic is required at evaporator temperatures.

12. Water solubility should be low as it can cause corrosion, acidic reactions.

The cut section of an air conditioner is shown in Figure 6. The critical part of an air conditioner is that it is a hermetically sealed unit there is no leakage of refrigerant even in ppl, parts per liter, this is assured by good brazing and seam welding joints. The electrical supply is through sealed welded Fusite connections. The suction, charging and discharge tubes are brazed to the shell at appropriate positions. The mufflers have sealed connections to the cylinder head and cylinder head is gasket sealed to the cylinder face. Bolt torque is calculated to ensure temperature, pressure and mechanical loads. The electric motor is concentrically aligned to the shaft; rotor is press fitted to shaft and stator is bolted to crankcase with uniform air gap to the rotor. The compressor is filled with lubrication oil which flows to bearings through the crankshaft. The Refrigerant flows from the evaporator into the shell cavity and gets sucked through the suction muffler into the cylinder gets compressed and flows out through the discharge muffler and goes through the discharge tube to the condenser. Certain amount of oil gets absorbed by the refrigerant and flows through the system and back to the compressor. If miscibility is bad at high temperatures they can get clogged in condensers blocking refrigerant flow and also causing shortage of oil to the bearings causing jammed compressors.

In analyzing the root causes of losses of power it is important to understand temperatures and pressures of different regions of gas flow paths. It is a challenging task to connect them without leaks many joining techniques are utilized. Figure 7 gives the pressure and temperature sensors connected to both suction & discharge mufflers.

![Figure 6. Cut section of an Air conditioner](image6)

![Figure 7. Sensors in suction & Discharge Plenum](image7)
The compressor is not welded but connected to a gasket sealed demountable shell shown in Figure 8. This configuration is leak tested at 300 Psig to make sure that it will not have any leakage during testing of unit on calorimeter or on appliance in the psychrometric room.

![Figure 8. Demountable shell for compressor.](image1)

2.9 Creating

The results obtained from measurements as analyzed in 2.5 are plotted on a PV graph to understand where the losses are occurring as shown in Figure 9. The deviation from isentropic process needs to be addressed in the compressor motor slip. The losses in discharge process at condenser are at discharge mufflers or in the discharge process.

![Figure 9. Detailed tests for evaluation of the new design](image2)

In Figure 11 the discharge valve is shown the leak proof surface sealing on the valve plate is possible if proper barreling of the valve is done with increased surface finish process the surface finish was improved from 15μm to 5μm b using corn for final barreling; it gives a mirror finish to the Silicon steel valve.

Similarly, the load of suction valve was CAD analyzed and a thinner 0.012” valve, Figure 9 was used instead of the 0.015” regular valve.

![Figure 10. Suction valve](image3)
The final stages of improvement are as shown in Figure 11.

- The Electric motor redesign of the windings gave improvement in power a major benefit of 151W.
- By changing the throw of the compressor 55W improvement was obtained.
- Cylinder head modification with direct suction entry gave 251W maximum benefit
- Suction and discharge valve changes gave 30W improvement.
- Making a new partly insulating cylinder head gave 77W benefit.

These changes were established by making a design batch of 10 numbers before handing over to the mechanical design department for production processes to be established.

3. CONCLUSION

The process of developing new models in high volume production specially in hermetic compressors is very critical as any lacuna in design or process can reverse the benefits as field returns can occur. A thorough remembering and understanding of basics of the subject and competition is the starting point. This is followed by application, analysis and evaluation of the existing and new models to obtain performance validation. This sequence is similar to the Blooms Taxonomy of pedagogy which institutes use in engineering institutes. This report is to high light to academic staff and students the benefit of Bloom’s Taxonomy as it can be used in their work place too.

Acknowledgement

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