Materials Today: Proceedings 42 (2021) 3097–3101

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Investigation of compressed air losses on production cost for Mosul dairy factory

Maan S. Al- Dabbagh, Zaha Kreshat, Rana Farhat *

Mechanical Engineering Department, College of Engineering, The University of Mosul, Almajmoa, Mosul 41200, Iraq

ARTICLE INFO

Article history:
Received 2 November 2020
Received in revised form 6 January 2021
Accepted 24 January 2021
Available online 12 March 2021

Keyword:
Compressed air
Energy cost
Energy losses
Food industry

ABSTRACT

A realistic field study was conducted on compressed air production stations in the Mosul Dairy Factory / Iraq, to determine the quantities of field losses resulting from the production of compressed air in the factory, and to determine the effect inlet temperature, pressure ratio, electric motor and leakage in the production line on the production cost, as all data were taken from the factory, and preparing a mathematical program to find and calculate the leaks in the compressed air in all parts of the factory production line. In addition to that the total cost of the compressed air losses during the production line was calculated. The results were listed in the form of quadrants that determined the relationship of the variables to losses in the production line. The typical lifetime compressed air costs in the year had been calculated and the percentage of each of the previous effects in the calculation of the saved cost, the results shows that the amount of the leakage, electric motor efficiency, intake temperature, and the reducing of setting pressure is about 16%, 54%, 25% and 5% respectively.

This work leads us to another future work in which how to address these losses in compressed air in the factory production line and work to reduce them by technical means in order to reduce the cost wasted due to these losses.

1. Introduction

1.1. Compressed air:[1]

Compressed air is an important source of energy and is indispensable in some manufacturing processes when operating machinery or when performing maintenance operations. Therefore, it is a major tool for many industries, with manufacture, while unlucky, its production price is among the highest in the manufactured cost:

1.2. Classification of a compressed air system:[1,2]

Compressed air systems consist of two sides

- The supply side, which includes compressors and air handling, which, correctly, it's managed will deliver pure, dry and in equilibrium state air with appropriate pressure in a reliable and cost effective.
- The demand side, which includes distribution, storage systems and end-use equipment. Correct management reduces air waste, selects proper use of compressed air.

1.3. Compressor Types

There are two types of compressor, Fig. 1: first one is Positive-displacement type and the second is Dynamic type [1]:

Positive displacement compressors: It come in two types:

- Reciprocating compressors: it classified into two types: Single-Acting, and Double-Acting
- Rotary compressors have become very popular, especially in the US industry, and have become the main parts in factories.

Dynamic compressors [1]: it includes two types:

- Centrifugal type.
- Axial compressors

Fig. 1 The compressor Types

* Corresponding author.
E-mail addresses: maandabbagh@uomosul.edu.iq (M.S. Al- Dabbagh), zahayousif@uomosul.edu.iq (Z. Kreshat), ranamohamed2785@uomosul.edu.iq (R. Farhat).

https://doi.org/10.1016/j.matpr.2021.01.737
2214-7853/

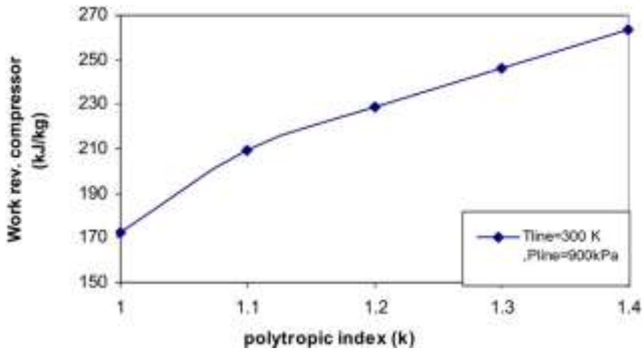

Fig. 1. Effect of Polytropic index on Work rev. Compressor.

1.4. Compressed air system leaks:[1,3]

Leakage occurs from all parts of the system of compressed air, but the biggest problematic parts are:

- Connections, holes, pipes, and fittings.
- Pressure regulators.
- Open condensate traps and shut-off valves.
- Pipe joins, connection parts, and thread sealants.

The leakages negatively affect the compressed air system, as shown below:

- Leakages are an important parts of the energy waste in the industries parts of the air compressed system, resulting in a waste of twenty to thirty percent the output of the compressor. In addition, the plant with bad maintenance has a leakage rate of twenty percent of compressed air capacity. While, leak identification besides, early maintained minimize leaks to less than ten percent of the output compressor production.
- Leaks contribute in other operating losses. Leaks lower the system pressure, which decreased the tools efficiently, and affected badly on the production.
- Leaks reduce the life of all system equipment, including the compressor.by increasing the working time of the equipment. It also leads to additional maintenance requirements and increased unplanned downtime. Finally.
- Leakages can add unnecessary compressive capacity.

2. Literature review

1. In 2016, the optimization of the compressed air system especially in the food industry or factory in Indonesia which was studied by (E. Widayati, and H.l Nuzahar) was done. A technical method has been used to optimize the compressed air system to determine optimum operating conditions for compressors and compressed air systems. This technology has significantly saved energy and costs [4].
2. (B. Singh, and O. Singh) focused on studying some energy storage and energy conversion systems. Especially using compressed air instead of other energy sources. And adopting it as a source of clean energy free of pollution, in addition to alleviating global warming [5]. The work concluded by:

- Compressed Air Energy Storage CAES, was a good use to increase the peak hour required for electrical power generation, regardless of all other options for energy storage.
- The possibility of operating the pneumatic engine by the vehicles that used electricity by replacing it with the compressed air storage tank that is filled using electrical energy during the rush hour requirements generated by the CAES which resulted from the wind turbine farm as a CAES system prepared for this purpose.
- The possibility of running the motorcycle air motor without pollution while finding the performance efficiency of the new compressed air motor suitable for operation ranges between 72%–97%.

1. Compressed Air Energy Storage CAES, has been recognized as one of the most efficient and economical technologies for conducting long term energy storage on a large scale to ensure the stability and reliability of the power grid by (Li, L., et al). CAES has been used for its high energy rating, small self-discharge, long life expectancy, relatively low capital cost and relatively high cycle efficiency.[6]
2. A study was conducted by (D. ešlija & et al.) to increase production efficiency of air compressed systems, extended component life cycle and reduce overall operating costs, that lead to increase the economic cost, work process quality. This application contains cost-effective activities to greatly increase component efficiency. Their study was conducted in the USA, European Union, China, and Serbia [7].
3. A study was conducted by (Y. Kim & et al.) To identify the main short comings of compressed air energy storage systems (CAES) and some innovative concepts of this type and were presented such as isolated and constant temperature, besides an another cases, that were addressed by analyzing the energy to see characteristics of each and comparing the different systems of CAES. [8].
4. The idea of operating a car by compressed air using a slider crank mechanism has been studied practically and theoretically before by (M. Nithin & et al.). Where extensive experimental research was conducted to investigate the feasibility of the air hybrid concept. Then work was done to develop models based on results from experimental data for the engine [9].
5. A new hydro-pump system with a compressed air energy storage system PHCA, was proposed by researchers (H. Wang, & et al.), to solve energy storage problems in wind power generation industry. In a region in China marked by drought and water scarcity, they performed thermodynamic analysis of these systems. Their results showed that the PHCA efficiency is related to the efficiency of the pump and the efficiency of the water turbine, considering the thermal process at the inlet and outlet [10].
6. (F. Doyle & J. Cosgrove) described a low-cost method for estimating the energy consumption of compressed air systems and lost because of leakage in the system,
7. and provided different means to reduce consumption of energy in a number of industrial facilities. They measured energy loss due to leakage in the system across five locations and identified approximately 500,000 kWh of energy wasted due to leaks of which thirty to sixty percent could be gained. And their results showed a 60% reduction in wasted electricity consumption at one site [11].
8. (J. You ,and T. Jianga) designed a 1 MW storage power plant, And formulate a strategic study of energy regulation to ensure the stable operation of power generation and electrical conditions. Also, they created a theoretical model for every unit of power plant.
9. In addition they simulated mathematically the hydraulic piston operation, and hydraulic piston rod operating speed between 0 and 60 s.[12].
10. (Fu H., et al.) Design a scheme for an isothermal compressed air energy storage power plant, which uses a liquid for compressed air, a hydraulic press to transmit the potential

energy, and a hydraulic turbine to generate static pressure. They also studied technical features and strategies for controlling the system. (13).

The work in the current research focuses on determining and calculating the quantities of compressed air losses in the field of the Mosul dairy plant / Iraq, where all data are taken from the factory, and a calculation program is prepared to find compressed air leaks in all parts of the factory's production line, effecting of the inlet temperature and pressure ratio, in addition to the total saving cost of compressed air losses during the production line.

3. Mathematical calculation

Compressed air is one of the most valuable sources of energy production for plants; the bigger energy factor loss in the producing is resulting from some important factors. All compressors that operate by electric motors, except for compressors that operate by natural gas, have losses in two directions; The first was external, including the leakage in the air transmission lines from production source to the places of its use, and the second is internal, which is the high temperature of the compressors station and the number of operating hours in addition to the aging of the machine, which in turn leads to a loss in energy production costs.

In this research, the study was carried out on the dairy production factory in Iraq as an example for the work of compressors: The compressors from Atlas Copco Company oil free air compressor Hanshin

Discharge Temperature: 60 – 105 °C
Discharge pressure: 7–9.9 kgf/cm^2
Installed Power: 31 kW
Capacity: 3000 litter / hr
Supply Voltage: 400 VAC/ 50 Hz

3.1. The compressor work:

The work input to compressor can be calculated by [13] :

$w_{rev,in} = \int v\,dp + \Delta K.E + \Delta P.E$ (kJ/kg)

when Δ K.E, Δ P.E are negligible the work is;

$$w_{rev;in} = \int V\,dp \quad (1)$$

The isentropic process is PV^k = constant, and integrated eq. (1), it becomes:

$$w_{comp,in} = kR(T_2 - T_1)/k - 1 = kRT_1/(k-1)\left[(P_2/P_1)^{(k-1)/k} - 1\right] \quad (2)$$

Where
k = specific heat ratio
R = gas constant
T_1 = inlet absolute Temperature (K)
P_1 = inlet absolute pressure (kPa)
Then the actual work wasted is

$$w_{comp;in} = w_{reversible;in}/\eta_{comp} \quad (3)$$

Energy and cost saving by fixing the air leakage location:

Several studies refers to that about 40%, of the lost through air leakage, in general, joints, elbows, flanges, valves, extension pipes, and the equipment devices connection.

The pressure drops test is the practical and realistic to detect compressed air leaks. The mass flowrate of air escapes through a leak becomes:

$$\dot{m}_{air} = C_{discharge}\left(\frac{2}{k+1}\right)^{1/(k-1)} \frac{P_{line}}{RT_{line}} A \times \sqrt{kR\frac{2}{k+1}T_{line}} \quad (4)$$

Where:

$C_{discharge}$ = discharge coefficient, Its value range 0.6 for sharp edges to 0.97 for a well- rounded circular [1].

A = cross sectional area m^2

P_{line} & T_{line} is the absolute pressure and absolute temperature in the air line respectively

$$Reduce\ power\ losses = power\ saved = \dot{m}_{air} \times w_{comp;in}$$
$$Reduce\ power\ losses = power\ saved = \dot{m}_{air} \times w_{comp;in} \quad (5)$$

3.2. Cost saving of compressed air

There is some procedure to saving cost of compressed air in the industrial facilities and energy. First must be determined the wasted power of compressor, second the usually electricity energy and cost saving can be Calculated from the following equation [15];

$$Cost(\$) = b.hp. \times 0.746 \times operating\ hours \times (\$/kWh) \times \%\ time \times \%\ full-load\ b.hp/motor\ Efficiency \quad (6)$$

Where:b.hp. = motor full-load horsepower, frequently higher than the motor horsepower.conversion between hp and kW = 0.746% time = percentage of time running at this operating.% full-load b. hp = percentage of full-load b.hp.

3.3. Effect of electrical motor

All compressors are driven by electric motors. And these motor is not able to convert all electrical energy into mechanical, as there are losses occurring. This is expressed by the efficiency of the electric motor, can be defined as the ratio of mechanical energy supplied to electrical energy used.

The high-efficiency motor reduces the operating cost in comparison with the standard operating cost, so it is desirable to replacing the existing a standard electric motor by another with a high efficiency to reduce energy losses and this energy saved is calculated from the following equation [14]:

$$w_{electric:\ saved} = w_{electric:\ standard} - w_{electric:\ efficient} \quad (7)$$

= Rated power $\times$ Load factor $\times$ $(1/\eta_{standard} - 1/\eta_{efficint})$

The energy saved by changing the efficient motor is calculated from the following equation:

$$Energy\ saving = w_{electric:\ saved} \times Annual\ operating\ hours \quad (8)$$

3.4. Effect of air intake temperature

The temperature of the space in which the equipment is operating has a great influence on the performance of the air compressor and the amount of energy spent in operating it.

Therefore, it was necessary to study the effect inlet temperature to the compressor on the amount of energy spent and saved, and the lower temperature of the inlet air was the better the compressor performance. For this reason, the air is drawn from outside station in which the compressor operates because the station temperature is higher than a degree of Atmospheric temperature.

The factor f reduction, shown in the following equation, explains the effect of inlet temperature on the energy expended.

$$f_{reduction} = (w_{comp;\ inside} - w_{comp;\ outside})/w_{comp;\ inside} = 1 - (T_{outside}/T_{inside}) \quad (9)$$

Where:T_{insid} and $T_{outside}$ are the absolute air temperatures inside and outside device respectively.

3.5. Effect of setting air pressure

Eq. (1) shows the calculation of the amount of work performed when using a certain pressure to compress a unit mass of air, and also noted that the largest pressure P2 when it existing from the compressor, the eq. (8) also refer to the power reduction if reduce the P2reduction, then the f reduction will be :

$$f_{reduction} = \frac{w_{comp,\ current} - w_{comp,\ reduced}}{w_{comp,\ current}} \quad (10)$$

$$f_{reduction} = 1 - \left[(P2_{reduction}/P1)^{(k-1)/k} - 1 \right] / \left[(P2/P1)^{(n-1)/n} - 1 \right] \quad (11)$$

Cost saving = (current cost) × f $_{reduction}$

4. Results and conclusion

Fig. 1 illustrates the effect of the Polytropic index or the specific heat ratio on the amount of work performed and shown in Eq. (2), as the greater the value of n, increase of the work until the value of n equals to 1.4, which is the value of air specific heat ratio at which the equations were be taken.

Fig. 2 refer to the effect of the Polytropic index on the compressor efficiency, and shown maximum value at 1.4, which this value taken in the mathematical equations at temperature and pressure line 300 K and 900 kPa respectively as a conditions of equation.

Fig. 3 indicates the effect of the temperature of the conveyor line on the amount of mechanical energy wasted. It is noted that increase in the line temperature, the amount of work increases accordingly when the outlet pressure is fixed, and this leads to a loss in the cost of producing compressed air.

Fig. 4 shows the relation between cost saving and the motor efficiency. The motors efficiency which are used to rotated compressor usually range from 70% to 90% and Electrical energy is not completely converted into mechanical energy, but rather part of it is converted into heat. For this reason, using less efficient motors than designed leads to cost losses.

Fig. 5 shows the effect of the amount of leakage occurring in the compressed air transmission lines represented by the hole area with the Leakage Area on the energy saving.

Fig. 6 refer to the relation between the intakes temperature and the cost saving, the figure shows the effect of the temperature outside the station (atmospheric air) on the amount of energy and the cost saving for this reason companies have made an air intakes from outside the station in order to reduce the cost.

Fig. 7 shows the effect of reducing air setting pressure ratio on the cost saving. The eqs. (9,10) shows this effect on the energy saving.

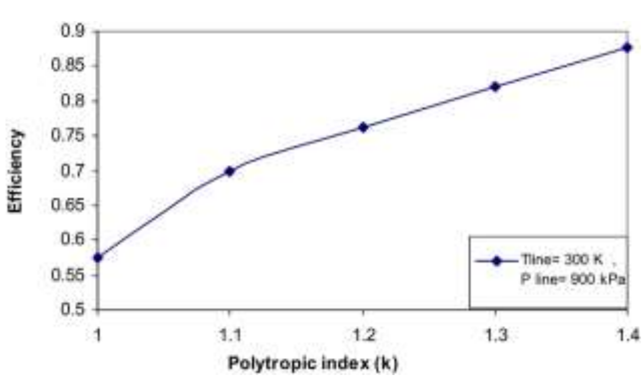

Fig. 2. Effect of Polytropic index on the Compressor Efficiency.

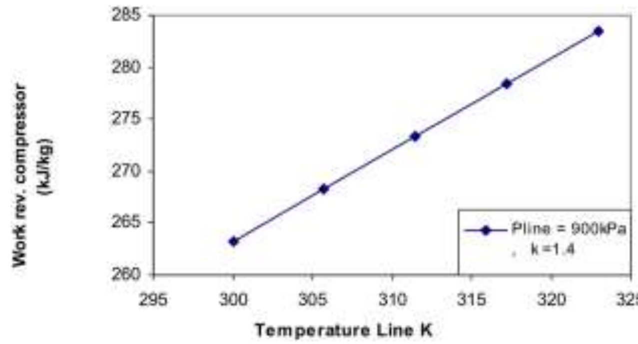

Fig. 3. Effect of Temperature Line on Work rev. Compressor.

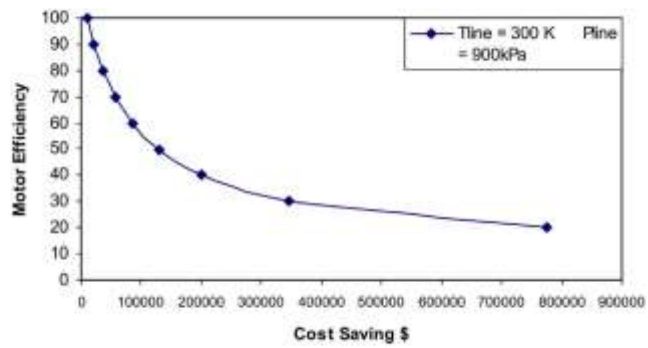

Fig. 4. Relation between Cost Saving and Motor Efficiency.

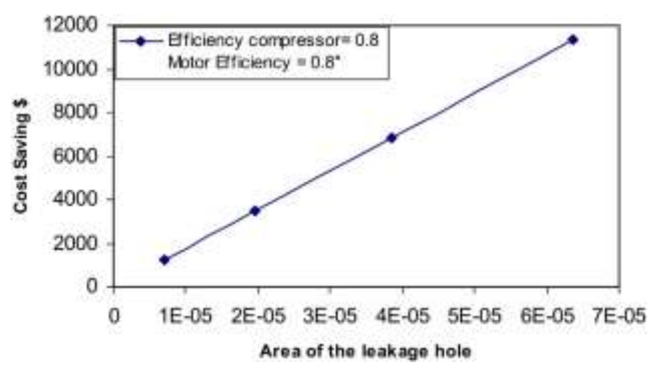

Fig. 5. Relation between the Leakage hole Area and The Cost Saving.

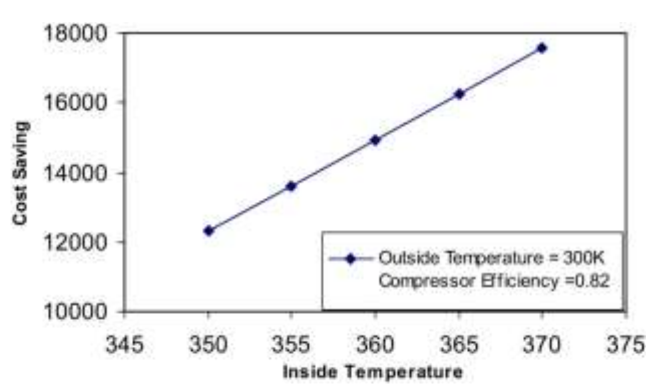

Fig. 6. Relation between the inside Temperature and The Cost Saving.

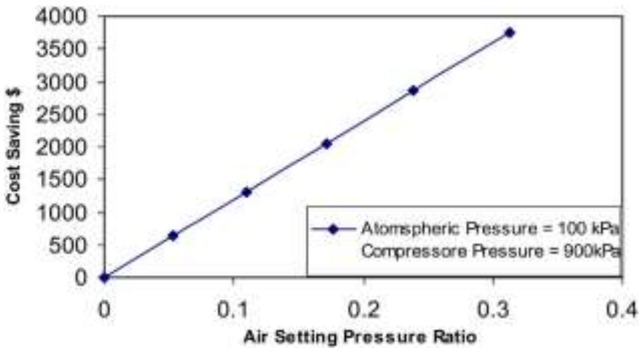

Fig. 7. Effect of Reducing Air Setting Pressure Ratio on the Cost Saving.

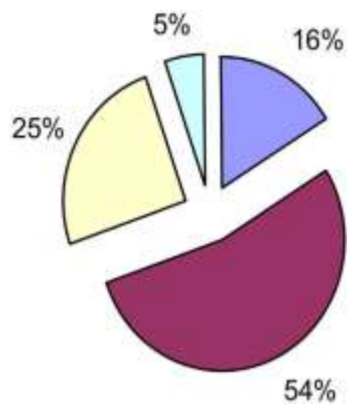

Fig. 8. Typical Lifetime Compressed Air Costs.

Fig. 8 refer to the typical lifetime compressed air costs in the year. The figure shows the percentage of each of the previous effects in the calculation of the saved cost as:

The amount of the leakage about 16%

The amount of electric motor efficiency about 54%

The amount of intake temperature about 25%

The amount of reducing setting pressure about 5%.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] B. Chris, G. Joseph, K. Henry, M. David, S. William, S. Gary, S. Dean, T. Tom, H.P. Van Ormer, Improving Compressed Air System Performance, a sourcebook for industry, U.S. Depart. Energy Energy Eff. Renew. Energy. (2003).

[2] Petr Eret (2016). A Cost-Effective Compressed Air Generation for Manufacturing Using Modified Microturbines: Applied Thermal Engineering.

[3] Manuel Unger, Peter Radgen (2018). Energy Efficiency in Compressed Air Systems – A Review of Energy Efficiency Potentials, Technological Development, Energy Policy Actions and Fture Importance: Conference Paper.

[4] Endang Widayati, Hasril Nuzahar (2016). Compressed Air System Optimization: Materials Science and Engineering 105.

[5] Bharat Raj Singh, Onkar Singh (2012). Study of Compressed Air Storage System as Clean Potential Energy for 21st Century: Global Journal of researches in engineering Mechanical and mechanics engineering Volume 12 Issue 1 Version 1.0.

[6] Li Li, Weiguo Liang, Haojie Lian, Jianfeng Yang, Maurice Dusseault (2018). Compressed air Energy Storage: Characteristics, Basic Principles, and Geological Considerations: Advances in Geo-Energy Research 2018, 2(2): 135-147.

[7] Dragan Šešlija, Ivana Ignjatović, Slobodan Dudić, Increasing the Energy Efficiency in Compressed Air Systems: Open access peer-reviewed chapter, Published: October 17th 2012 (2012). https://www.researchgate.net/publication/268978204.

[8] Young-Min Kim, Jang-Hee Lee, Seok-Joon Kim, Daniel Favrat, Potential and evolution of compressed air energy storage: energy and exergy analyses, Entropy 14 (8) (2012) 1501–1521, https://doi.org/10.3390/e14081501.

[9] M.R.Saroj Nithin, G.Sai Krishnan, S.Prabu, G.Suresh (2018).Vehicle Operating on Compressed Air by Inversion of Slider Crank Mechanisim, Journal of Applied Science and Computations Volume 5, Issue 4, April /2018 ISSN. NO: 1076-5131 Page No:223- 229.

[10] Huanran Wang *, Liqin Wang, Xinbing Wang and Erren Yao (2016). A Novel Pumped Hydro Combined with Compressed Air Energy Storage System: Energies 2013, 6, 1554-1567; doi:10.3390/en6031554

[11] Frank Doyle and John Cosgrove, (2017). An approach to optimizing compressed air systems in production operations: International Journal of Ambient Energy, 2017.

[12] [12] Jiayu You, Tong Jianga (2019). Power Regulation Strategy of Virtual Pumped Storage Power Station Based on Compressed Air Energy Storage: IOP Conf. Series: Materials Science and Engineering 677 (2019) 032030

[13] Fu Hao, Tong Jiang, Yan Cui, Bin Li, Design and operational strategy research for temperature control systems of isothermal compressed air energy storage power plants, J. Therm. Sci. (2019).

[14] Yunus, A., Cengel, Mechail, A., Boles, Mehmet,K.(2019), Thermodynamics: An Engineering Approaoach. Ninth Edition, McGraw Hill, 2019.

[15] Energy Efficiency Best Practice Guide, (2009). Compressed Air System, Sustainability Victoria, (Australasia) Lt.