International Journal of Thermodynamics and Chemical Kinetics

ISSN 2456-6977
Volume 10, Issue 2, 2024
DOI (Journal): 10.37628/IJTCK

https://chemical.journalspub.info/index.php?journal=JTCK

Research IJTCK

Computation of Compressor Components Failure and Maintenance Characteristics

Ukpaka C. P.[1], Victor Chukwuemeka Ukpaka[2], Abraham Peter Ukpaka[3,*]

Abstract

The computation of the compressor components' failure and maintenance characteristics as related to the major parts are described in this research. The research projected the root cause of the compressor components failure as well as projected the necessary measures to reduce such occurrences in the gas compressor operation. The parameters of the Mean time between failure, failure rate, downtime maintenance, reliability, unreliability, and availability were commuted with respect to the number of failures of each compressor component per year. The research revealed that an increase in the unreliability of each compressor component was experienced with an increase in sampling years from 2016 to 2020. This increase in unreliability will increase the cost of operational maintenance of the plant as well as reduce the rate of production and the performance of the system. The research further revealed that failure of some components induces the performance of another component, and some cases causes the other component to fail as well. The computation also shows the trend in which the component investigated failed and the value of each component's characteristics in terms of evaluated values. The compressor components considered in the investigation include reciprocating gas compressors' "O" rings, valve, piston, crankshaft, cylinder, and seal. The research has shown that lack of adequate maintenance as well as overloading the operation units of the plant not recommended to the operational may be the cause in failures of the component of the gas reciprocating compressor components

Keywords: Computation, compressor, components, failure, maintenance, characteristics

INTRODUCTION

The development of technologies for compressor's expanding maps goes back to the 1970s. Historically and into the modern era, the focus has primarily been on systems that can induce swirl in front of the compressor. To achieve this, inlet guide vanes (IGV) were strategically positioned directly in front of the compressor impeller to create a swirl in the incoming air [1].

A novel approach was introduced based on the principle of dynamically adjusting the trim of a compressor as needed [2]. For experimental research, a conical body was developed and placed in front of the impeller. This design accelerates the incoming air while preventing it from entering the portion of the impeller operating at high peripheral speeds [3]. As a result, this reduces flow separation and enhances the inflow angle at the blade channel. The conical body occupied nearly 40% of the inlet cross-section [4], resulting in a surge limit shift of

***Author for Correspondence**
Abraham Peter Ukpaka
E-mail: abraham.ukpaka@lpunetwork.edu.ph

[1]Professor, Department of Chemical/Petrochemical Engineering, Rivers State University Port Harcourt, Rivers State, Nigeria.
[2]Research Student, College of Engineering, Computer Studies and Architecture, Department of Industrial Engineering, Lyceum of the Philippines University Cavite, Philippines.
[3]Research Student, College of Engineering, Computer Studies and Architecture, Department of Computer Engineering, Lyceum of the Philippines University Cavite, Philippines.

Received date: September 26, 2024
Accepted date: October 22, 2024
Published date: November 15, 2024

Citation: Ukpaka CP, Victor Chukwuemeka Ukpaka, Abraham Peter Ukpaka. Computation of Compressor Components Failure and Maintenance Characteristics. International Journal of Thermodynamics and Chemical Kinetics. 2024;10(2):1–12p.

approximately 33% and a 7%-point increase in isentropic compressor effectiveness [5].

Additionally, a variable system that allows for trim variability (VTC) was proposed. The method of trim adjustment was later incorporated into further studies, where the streamlined cone body was replaced with a more compact design [6]. In a closed position, the flow is directed through an orifice, while in the open position, the inlet cross-section is fully released [7]. For these designs, a comparable potential regarding surge limit shifts was identified for the VTC system. Various strategies for surge limit shifts have been evaluated, including VTC, IGV, and exit guide vane systems (EGV), along with their combinations, both numerically and experimentally [8]. Among these measures, the VTC system exhibited the highest potential. Experimental investigations corroborated these findings [9].

In a practical application, the original two-stage charging system of a 1.4-liter gasoline engine producing 125 kW was replaced with a single-stage system utilizing variable turbine geometry (VTG) and an expansion mechanism on the compressor (IGV or VTC). The results indicated that the optimal method for achieving the original base load was through the combination of VTG and VTC [10–16]. Gas compressor is a major unit in the gas industry operation and the failure of any component influences production as well as increases downtime because of its usefulness to the plant operation [17–21]. There is a need to check the reliability of each unit at the section where it is stored to avoid failure and loss of man hours. In most operations, the failure of the gas compressor unit influences other unit components that their sources of operation depend on the energy released from the gas compressor [22–24]. However, it is necessary to carefully examine the causes of the gas compressor failure, by checking the reliability and unreliability of the unit components to avoid sudden short down of operation [25–26].

MATERIALS AND METHODS

Materials of Gas Compressor Components

The various gas compressor components sampled as demonstrated below in terms of the cross-sectional regions in Figure 1. Indeed, plate 1 demonstrates the "O" rings, plate 2 illustrates the valve, plate 3 shows the crankshaft, plate 4 showcases the cylinder, and plate 5 demonstrates the seal as well as Figure 2 shows a well-labeled diagram of the valve and Figures 1–3 illustrate the well-labeled diagram of the piston.

Typical gas reciprocating compressor cross-section.

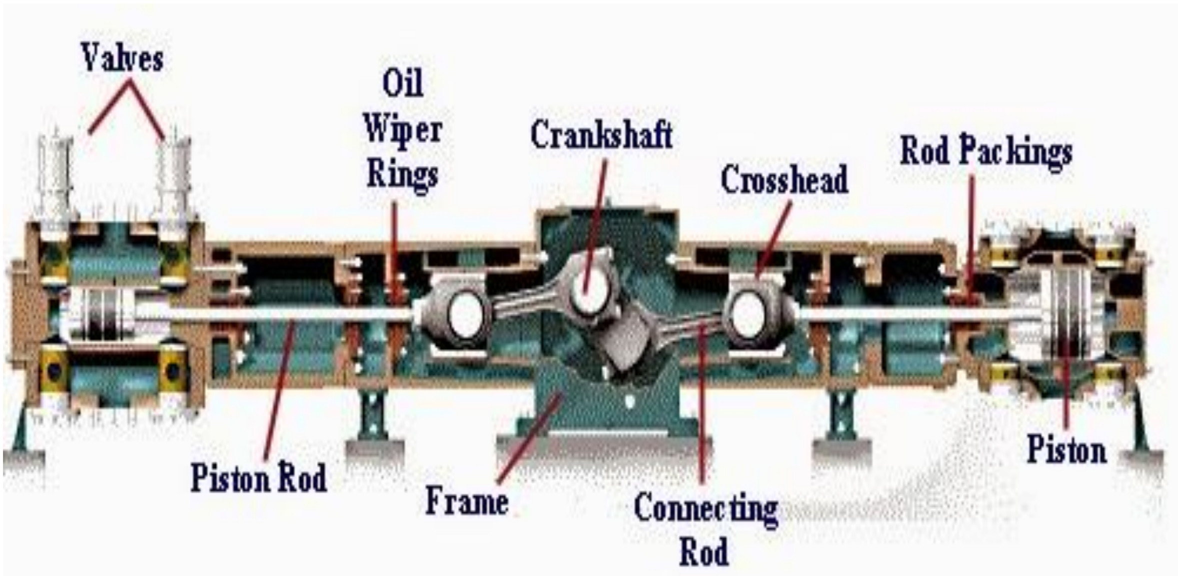

Figure 1. Typical gas reciprocating compressor cross-section.

Figure 1. (a) Plate 1: reciprocating gas compressors' "o" rings, (b) plate 2: gas reciprocating, and (c) compressor valves.

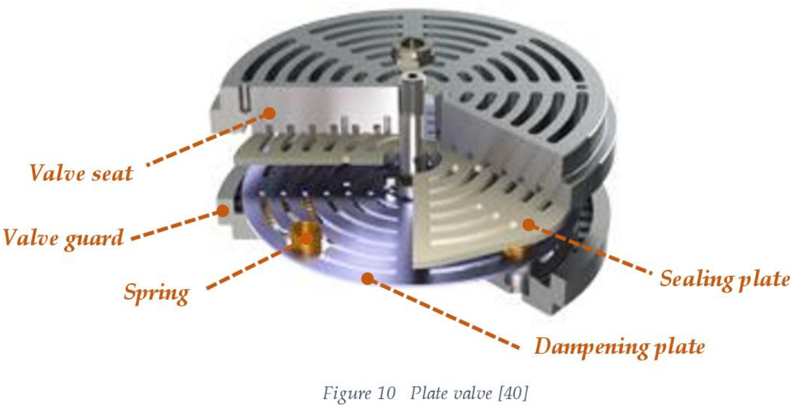

Figure 2. Gas reciprocating compressor valve (with components).

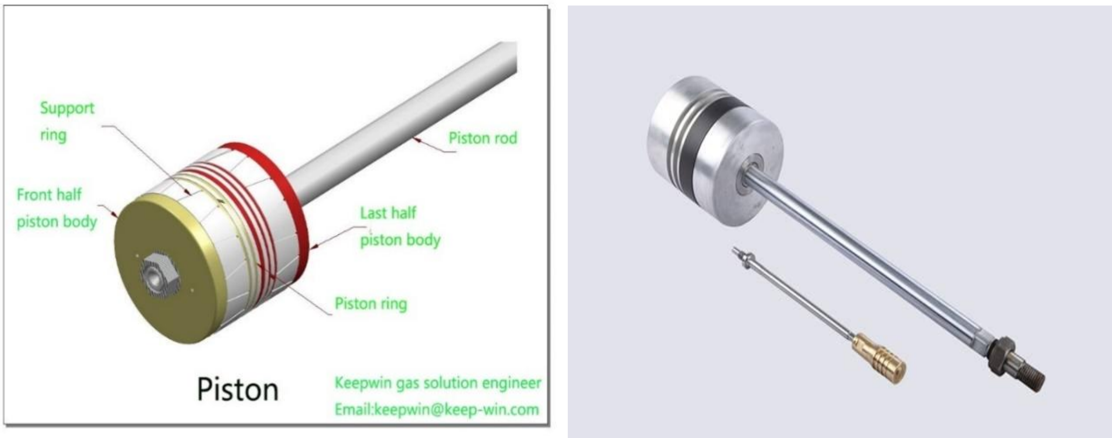

Figure 3. Gas reciprocating compressor pistons.

Review of Applied Maintenance Engineering Studies

A collaboration was made with a private company called RC to analyze the performance of their used reciprocating compressor and meant to identify and evaluate the effects of reliability, availability, and maintainability (RAM) study presented the most relevant aspects and findings by assessing the operative performance of the reciprocating compressor system. Similarly, it goes over the maintenance activities, outlined failures, and main measures contributing to putting at risk the production process. It emphasized the generated preventive maintenance responsibilities and planning on reciprocating compressor API 618 and recognized the desire for a structural method to implement RAM. The method used was bibliographic research, documented and content analysis of storing most of the maintenance problems. Figures 4–6 research output reproduced the importance of using RAM for plant lifespan control and reviewed the RAM performance and emphasized the usefulness of learning RAM principles to the process engineers to apply.

Figure 4. Gas reciprocating compressor crankshaft.

Figure 5. Gas reciprocating compressor cylinder.

Figure 6. Gas reciprocating compressor bearing and gas reciprocating compressor seals.

Integrity supervision is defined as a somewhat advanced risk prevention and risk administration method and completed a study on the risk-based inspection (RBI) method for gas compressor stations and reproduced the applied integrity administration of a gas compressor station was inadequate. Thus, he reviewed the elementary principle of RBI in the gas compressor station and determined the process loops and corrosion mechanisms. The possibility of failure is calculated by means of using the modified coefficient and the significance of failure is determined in the quantitative method. Actual measures taken to remove the influence of risk. The results indicate that the cumulative risk and average risk were much higher mostly because of the potential of piping and equipment for sulfide stress corrosion cracking. As stated by the analysis output, it institutes that about 10% of the compressor accounted for about 80% of the risk in the plant and by developing a targeted inspection plan would efficiently control the risk and decrease costs.

Besides that, a study focused on the method of improving efficiency through overall equipment effectiveness (OEE) with the help of lean manufacturing performance in compressor manufacturing industries. Lean manufacturing technique has been used to identify the waste and losses and reduce such losses from the process. The study carried out two high-pressure air compressor manufacturing units and addressed three features; namely, the availability, performance, and quality which quantify OEE. The investigation result showed that the OEE has improved from 45.9% to 55.8% in inspecting the influence of the total equipment efficiency which compared before and after implementing the lean tools. The end results gained a 75% decrease in the tool searching period, 23% of downtime and efficiency has been increased in the range of 12.5% and overall equipment efficiency improved by 17.7%. The equations below were used to acquire the OEE:

$$\text{Availability} = \frac{operating\ time}{total\ available\ time - planned\ down\ time} \quad (1)$$

It considered the performance rate as the manufacture period of net output of equipment to its entire availability time as per the below description:

$$Performance = \underline{Ideal\ cycle\ time \times Total\ cycle\ time}\ Operating\ time \quad (2)$$

$$Quality = \underline{Total\ \text{parts}\ run - \text{T}otal\ defe\text{cts}}\quad Total\ \text{parts}\ run \quad (3)$$

$$OEE = Availability \times Performance \times Quality \quad (4)$$

RESULTS AND DISCUSSION

The results and discussion of research as presented in Tables 1–5 shows the parameters of interest monitored which include the failures of compressor 1 to 4 as related to operation time, idle time of the unit, expected operation time, expected maintenance time, and number of failures per each year. For 2016, the compressor failure order is:

4 >1 >3 >2, for 2017 4 >3 =1>2, for 2018 4 =3 >1 >2, for 2019 4 >3 >2 =1, and for 2020 4 >3 >1 >2.

Table 1. Failure data for compressor in 2016.

Failed System	Failure Time (hr.)	Operation Time (hr.)	Idle Time (hr.)	Expected Operation Time (hr.)	Expected Maintenance Time (hr.)	Number of Failures
Compressor 1.	214.43	565.77	7091.8	7872.00	768.00	12
Compressor 2.	710.01	470.12	6691.87	7872.00	768.00	5
Compressor 3.	1042.00	667.65	7497.65	7872.00	768.00	11
Compressor 4.	2243.43	659.23	4969.34	7872.00	768.00	13

Table 2. Failure data for compressor in 2017.

Failed System	Failure Time (hr.)	Operation Time (hr.)	Idle Time (hr.)	Expected Operation Time (hr.)	Expected Maintenance Time (hr.)	Number of Failures
Compressor 1.	1129.00	601.40	6141.60	7872.00	768.00	10
Compressor 2.	667.65	942.05	6262.30	7872.00	768.00	8
Compressor 3.	393.10	2962.27	6260.91	7872.00	768.00	10

	1165.41	506.39	968.51			

Table 3. Failure data for compressor in 2018.

Failed System	**Failure Time (Hr.)**	**Operation Time (Hr.)**	**Idle Time (Hr.)**	**Expected Operation Time (Hr.)**	**Expected Maintenance Time (Hr.)**	**Number of Failure**
Compressor 1.	4298.91	1322.51	2250.58	7872.00	768.00	7
Compressor 2.	2162.68	3912.25	1797.07	7872.00	768.00	7
Compressor 3.	1590.93	1531.20	4749.87	7872.00	768.00	9
Compressor 4.	6569.82	1250.10	52.08	7872.00	768.00	9

Table 4. Failure data for compressor in 2019.

Failed System	**Failure Time (hr.)**	**Operation Time (Hr.)**	**Idle Time (hr.)**	**Expected Operation Time (Hr.)**	**Expected Maintenance Time (hr.)**	**Number of Failures**
Compressor 1.	1307.06	5003.85	1561.09	7872.00	768.00	7
Compressor 2.	2596.83	1586.33	3688.84	7872.00	768.00	7
Compressor 3.	3458.60	1421.72	4880.32	7872.00	768.00	9
Compressor 4.	5995.88	1250.10	629.02	7872.00	768.00	13

Table 5. Failure data for compressor in 2020.

Failed System	**Failure Time (hr.)**	**Operation Time (Hr.)**	**Idle Time (hr.)**	**Expected Operation Time (Hr.)**	**Expected Maintenance Time (hr.)**	**Number of Failures**
Compressor 1.	466.93	4083.54	3321.52	7872.00	768.00	6
Compressor 2.	890.68	2682.15	2572.82	7872.00	768.00	5
Compressor 3.	2990.83	3803.29	1102.50	7872.00	768.00	7
Compressor 4.	1234.21	1500.60	5137.19	7872.00	768.00	9

Table 6 shows each component failures analysis of the reciprocating gas compressors' "O" rings, valve, piston, crankshaft, cylinder, and the seal and frequency valve each year from 2016 to 2020 for component grouping of 1 to 4. The failure of each component monitored changes as the period of increase in some cases as well decreases with an increase in sampling time. Table 7 demonstrates the four compressor running hours in five years and the compressor running hours increase as the year of sampling increases as well.

Table 6. Compressors' components failures analysis.

Number of Components' Failures Recorded from the Year 2016 to 2020						
Years	**Components**	**Comp 1**	**Comp 2**	**Comp 3**	**Comp 4**	**Frequency**
Year 1 (2016)	Valves.	3	2	2	3	10
	Seal.	2	1	2	3	8
	Pistons.	1	0	0	1	2
	Bearing.	2	1	3	2	7
	"O" rings.	3	1	2	3	9
	Cylinders.	1	0	2	1	4
	Total					40
Year 2 (2017)	Valves.	2	2	2	0	6

	Seal.	3	1	2	0	6
	Pistons.	0	1	1	0	2
	Bearing.	2	2	1	0	5
	"O" rings.	2	2	3	0	7
	Cylinders.	1	0	1	0	2
Total						28
Year 3 (2018)	Valves.	2	1	3	1	7
	Seal.	2	1	2	1	6
	Pistons.	0	0	1	1	2
	Bearing.	0	1	1	2	3
	"O" rings.	2	3	2	3	7
	Cylinders.	1	1	0	1	3
Total						28
Year 4 (2019)	Valves.	2	1	1	1	5
	Seal.	2	2	3	5	5
	Pistons.	0	0	0	1	1
	Bearing.	1	1	2	1	4
	"O" rings.	2	3	2	4	5
	Cylinders.	0	0	1	1	2
Total						22
Year 5 (2020)						
	Valves.	1	1	1	2	5
	Seal.	2	2	3	0	4
	Pistons.	0	0	0	1	1
	Bearing.	1	1	0	1	3
	"O" rings.	2	1	2	4	4
	Cylinders.	0	0	1	1	1
Total						18

Table 7. Four compressors running hours in five years.

Compressors Running Hours Yearly (5 Years)									
Years	**Compressor 1**	**Compressor 2**	**Compressor 3**	**Compressor 4**	**Total Operational Time (hrs.)**	**Total Component Failures**	**Total Down Time (hrs.)**	**Mean Down Time (hrs.)**	**MTBF**
Year 1	214.43	710.01	1042	2243.43	4209.9	40	1008	25	105.25
Year 2	1129	667.65	393.1	1165.41	3355.2	28	1440	51.4	119.83
Year 3	4298.91	2162.68	1590.93	6569.82	14622	28	1080	38.6	522.23
Year 4	1307.06	2596.83	3458.6	5995.88	13358	22	510	23.2	607.20
Year 5	466.93	890.68	2990.83	1234.21	5582.7	18	625	34.7	310.15
Total	7416.33	7027.85	9475.46	17208.75	41128	136	4663	173	1664.6

Figure 7 shows the program input and output of human–machine interface (HMI)-1 AND Figure 8 shows the HMI-2 run-out information of the system with respect to the computation order. Tables 8–11 demonstrates the failures and the root causes of failure with the prevention and correction measures for the compressor components unit monitored, such as reciprocating gas compressors' "O" rings, valve, piston, crankshaft, cylinder, and seal.

Figure 7. HMI – 1.

Figure 8. HMI – 2.

Table 8. Cylinder failures modes and the causes of failure.

	Failure Mode	Failure Caused	Failure Effect
i.	Cylinder fails to move.	Spring loaded valve fails to open	Loss of gas output.
ii.	Cylinder leakage.	Mechanical wear. Damage seal.	Reduced compressor efficiency.

iii.	Liquid entering one or more compression cylinders.	Seal failure.	Permanent valve damage. Reduced compressor efficiency.
iv.	Gas leakage.	Piston–cylinder clearance. Cylinder head loose.	Cracking. Noisy compressor.

Table 9. Piston failure modes and the causes of failure with remedies.

	Failure Modes	Caused of Failures	Remedies
i.	Piston crown damage.	Installing the wrong piston type or piston with incorrect dimensions. Faulty cooling system. Broken valves.	Ensure the right piston and correct piston dimensions. Ensure that the cylinder head parts are always working correctly since they are the major cause of crown damage.
ii.	Piston skirt damage.	Incorrect piston (too small) for the cylinder. Excessive rocking of piston. Bent connecting rod. Insufficient compression. Uneven or pitted cylinder walls. Lack of lubrication.	Ensure the proper size of the piston and cylinder. Ensure that piston installation is done in the right position. Ensure sufficient compression. Ensure proper lubrication.

Table 10. Bearing failures modes and the causes of failure with remedies.

S. N.	Effects	Caused	Remedies
i	Worn	Installing the wrong bearing type or bearing with incorrect dimensions. Lack of lubrication. Misalignment.	Ensure the right bearing and correct bearing dimensions. Proper lubrication. Ensure proper alignment and review the manufacturer’s recommendation.
ii	Fatigue	Lack of lubrication. Overloading.	Ensure that bearing installation done in the right position. Ensure proper lubrication. Check design assumptions.
iii	Cracking	Overloading.	Check lubrication procedures.
		Excessive bearing clearance.	Repair or replace.

Table 11. O-ring failures modes and the causes of failure with preventions/corrections.

S. N.	Failures Mode	Failures Caused	Prevention/Correction
i.	Rapid gas decompression.	Elevated temperature increases the damage. Explosive decompression or gas expansion rupture is caused by high-pressure gas trapped within the internal structure of the	Increase decompression time to allow trapped gas for the workout of seal material. Choose a seal material with good resistance to explosive decompression. Minimize the time application is held under pressure.

		elastomeric seal element. Excessive trapped gas may cause destruction of the seal.	
ii.	Abrasion.	Improper finish of the surface in dynamic contact with the “O”-ring. Improper lubrication provided by system fluid. Excessive temperatures. Contamination of system fluid by abrasive particles.	Use proper surface finish. Provide adequate lubrication by using proper system fluid. Consider the use of internally lubricated O-rings to reduce friction and wear. Check for contamination of fluid and eliminate the source. Install filters, if necessary. Consider changing to an “O”-ring material with improved abrasion resistance.
iii.	Installation.	Insufficient lead-in chamfer. Blind grooves in multi-port valves. Oversize or undersize of “O”-rings. “O”-ring twisted/pinched during installation. “O”-ring not properly lubricated before installation. “O”-ring not properly lubricated before installation.	Break all sharp edges on metal components. Provide a 20° lead-in chamber. Check all components for cleanliness before installation. Use an “O”-ring lubricant. Double check the “O”-ring to ensure the correct size and material.
iv.	Fluid incompatibility	“O”-ring exhibiting chemical attack. Shrinking. *Swelling:* The “O”-ring will swells in size because the incompatible elastomer is absorbing the fluid.	This also results in the O-ring material softening and becoming gummy, which ultimately leads to other failure modes. Other times, the O-ring material will become embrittled, or cracked, sometimes taking a compression set. Therefore, used the O-ring that meets up with the required materials.

CONCLUSIONS

The data set in this research is relatively small and the results are only representative of just five components and did not extrapolate to reflect the situations in other components. To improve the performance of the reciprocating gas compressor or control breakdown:

i. The research has drawn significant database information, and the system recommended that the times past of failures of compressors must be data-based in such a technique that access to the information concerning the number of hours before a certain failure happened.
ii. A study of reliability-centered maintenance (RCM) that incorporates methodologies of implementation of preventive, predictive, and corrective maintenance in one pack. The research has demonstrated the best mechanism by implementing an RCM program, this can help in identifying the critical parts and life-limited components, as well as identifying the appropriate

maintenance activities and scheduling to optimize reliability.
iii. The reliability of gas reciprocating compressor components.

The analysis of reliability in gas reciprocating compressor components must incorporate the HMI within a monitoring system known as a programmable logic controller (PLC). The primary goal of this setup is to enable operational personnel to monitor all critical components effectively, ensuring they remain accountable for the associated machinery. By integrating HMI with PLC systems, operators can access real-time data on component performance, facilitating timely maintenance decisions and enhancing overall system reliability. This proactive monitoring approach helps identify potential issues before they escalate, ultimately leading to improved operational efficiency and reduced downtime.

REFERENCES

1. Haping RA. Flow and plate motion in compressor valve, doctoral thesis. Netherlands: University of Twente, Enschede. ern, M. Horn, W. Hiller, S. J. Staudacher, S., “Effect of Tip İnjection on the Performance of a Multi-Stage High-Pressure Compressor”, Cease Aeronaut J. 2011;2(1–4):99–110.
2. Herbst F, Eilts P. Experimental investigation of variable geometry compressor for highly boosted gasoline engines. 2015; SAE International, Technical Paper. 2015-01-1289. doi:10.4271/2015-01-1289
3. Herbst F, Stöber-Schmidt C, Eilts P, Sextro T, Kammeyer J, Natkaniec C, et al. The potential of variable compressor geometry for highly boosted gasoline engines. 2011. SAE International, Technical Paper. 2011-01-0376. doi:10. 4271/2011-01-0376
4. Hinson J M, Jameson TL, Whitney P. Somatic markers, working memory, and decision making. Cognit Affec Behav Neurosci. 2002;2(4):341–53.
5. Hou Xiongpo, Gu Zhaolin, Gao Xiufeng, Feng Shiyu, Li Yun. Analysis of efficiency and power factor of reciprocating compressor unit under variable frequency and variable-conditions. 2008; International Compressor Engineering Conference. Paper 1878
6. Jones BA. Single stage experimental evaluation of variable geometry inlet guide vanes and stator blading. Part VI, final Report NASA CR-54559, PWA-FA-2641, Pratt and Whitney Aircraft; NASA Contract NAS3-7604, NASA-CA-54559. 1970.
7. Iwakiri Y, Otsuka M, Kashimoto A. Enhancement of surge margin for an automotive turbocharger centrifugal compressor by an inlet anti-swirl plate. Trans Soc Auto Eng Japan. 2017;48(2)265.
8. Karstadt S, Weiske S, Münz S. Turbocharger with variable compressor geometry – another contribution to improved fuel economy by the boosting system. In:27th aachen colloquium automobile and engine technology. Aachen. 2018;1191–1214.
9. Karuthapandi S. Enhancing overall equipment effectiveness (OEE) in compressor manufacturing industries. Res Develop Mat Sci. 2018;6(32):47–78.
10. Keerqinhu E. Fault-Diagnosis for Reciprocating Compressors Using Big Data. In: 2016 IEEE Second International Conference on Big Data Computing Service and Applications. 2016. pp. 72–81.
11. Kern JK, Fletcher CL, Garver CR, Mehta JA, Grannemann BD, Knox KR, et al. Prospective trial of equine-assisted activities in autism spectrum disorder. Alt Therap Heal Med. 2011;17(3):14–20.
12. Kindl H, Schorn N, Schulte H, Serrano JR, Margot X, Donayre JC. Influence of various compressor inlet designs on compressor performance, conference on Thermo- and Fluid Dynamic processes in diesel engines (THIESEL). 2004. pp. 103–116.
13. Koga T. High pressure, high standards: high pressure screw gas compressors. Hydrocarb Eng.2009;14(2):73–8.
14. Lekic U, JBW Kok. Heat Flows in Piston Compressors. In: Proceedings of the 5th European Thermal Sciences Conference. The Netherlands: 2008;64(1):22–31.

15. Liang K, Stone CR, Hancock W, Dadd MW, Bailey PB. Comparison between a crank-drive reciprocating compressor and a novel oil-free linear compressor. Int J Refrig. 2014;45:25–34.
16. Liu B, Feng J, Wang Z, Peng X. Attenuation of gas pulsation in a reciprocating compressor piping system by using a volume-choke-volume filter. J Vibrat Acoust. 2012;134(5):9.
17. Larky M, Ahsaee M, Lolaki A. Javidrad H. Developing a new technique to calculate overall equipment effectiveness (OEE) for air compressors. 2018;5(3):20–25.
18. Kostyukov VN, Naumenko AP. About the experience in operation of reciprocating compressors under control of the vibration monitoring system. Procedia Eng. 2016;1(52):497–504.
19. Loukopoulos P, Gwanie F, Ranshi V. Reciprocating compressor prognostics of an instantaneous failure mode utilizing temperature only measurements. Appl Acoust. 2017;147:77–86.
20. Koga T. High pressure, high standards: high pressure screw gas compressors. Hydrocarb Eng. 2009;14(2):73–8.
21. Lochmann K, Ziehe G. High-pressure compressor for CNG filling station: development, design, application. Gaswarme İnt. 1998;47(4/5):267–71.
22. Martina F, Mike H. Reciprocating compressors in use in photovoltaics and for biogas feed. 2012. NEUMAN & ESSER GmbH & Co. KG, Übach-Palenberg, Germany.
23. Naumenko AP, Kostyukov VN. The Piston Compressor: The Methodology of the Real-Time Condition Monitoring, Physical. Conf Ser. 2012;3(64):12–130.
24. Ooi KT. Heat transfer study of a hermetic refrigeration compressor. Appl Therm Eng. 2003;23:1931–45.
25. Pampreen RC. The Use of variable inlet guide vanes for automotive gas turbine engine augmentation and load control. 1976. Detroit, SAE International, Technical Paper No. 760285.
26. Prata Jr, JA, Fernandes LHS, Komagome CM, Höfling-Lima AL, Gomes JAP. Uso de membrana amniótica no tratamento de complicaçõespós-trabeculectomia.Arquivos Brasileiros de Oftalmologia. 2001;64:437–41.

