A Non-The Cost Analysis of CNG Compressors with Changing Stage Numbers During Compressing

Battal Dogan and Irfan Unal

Mechanical Engineering Department, Kirikkale University, Kirikkale, 71451 Turkey.
Mechanical Engineering Department, Kirikkale University, Kirikkale, 71451 Turkey
Phone: +90 (318) 357-3571; Fax: +90 (318) 357-2459, bttldgn@gmail.com, irf.unal@hotmail.com

Abstract— CNG is compressed natural gas. CNG compressor is the equipment which provides to compress the low pressure natural gas into high pressures. The usage of gases in high pressures is a current issue in industrial institutions and transportation. However, the economical analysis of rising to high pressure is very important in terms of energy costs. In this study, the working parameters of CNG compressors with high pressures that have 3 and 4 stage numbers have been examined experimentally and the gasoline cost during compressing has been calculated. In the compressors with changing stage numbers, it is aimed that the gasoline cost should be the comparison element beside the working parameters like heat and pressure

***Index Terms*—Compressor, CNG, Energy Cost**

I. INTRODUCTION

Compressors are the devices that increase the pressure of the compressible gases. The compressor of every gas has a different design, so it is necessary to design it suitable to the characteristics of the gas compressed. High pressure gas compressors are usually used for maximum storage. These compressors are used for compressing many gasses like air, nitrogen and natural gas and for reaching the high values like 200-500 bars. Piston type compressors for CNG have been used commonly.

CNG compressors in Figure 1 are used in high pressures. The characteristics of compressors' internal surface must be suitable so that the cylinders used in the compressors can endure to the high pressure and heat. The cooling of cylinder's internal surface must be provided. Compression process occurs by the help of crank-rod mechanism driven from electric motor. Compressors are manufactured on different stages. When determining the stage numbers, several parameters like pressure, heat, flow and noise are taken into account.

About 7 million vehicles throughout the world work with CNG according to the latest statistics. It is estimated that the number of vehicles with CNG in Europe in 2020 will be 23,5 million. Natural gas consumption will be about 47 million m3 in this situation. CNG usage in public transport especially in big cities is very important in terms of exhaust emission

The flow in CNG compressors changes depending on cubic capacity, gas input capacity, gas output field of the cylinder and power and rotation speed of compressor motor. High flow of CNG compressor enables gas storage in high rates on a shorter time, but providing a high flow increases the compressor cost.

Gas input pressure in CNG compressors is very important. If the gas pressure from main distribution frame increases, energy and time spent for the required pressure value decreases. The temperature of gas on entry in gas compressors vary from season to season. In summer when the heat of gas is high, the temperature of gas compressed in the stages of compressor increases to high values. In winter, there is no problem like this. Especially in summer, when filling is done, the cooling measurements must be increased during compression.

A. Literature Review

There are a lot of studies on high pressure compressors in literature. The Natural gas devices used in the USA were examined and the information on fertile gas compressors was given comparatively [1]. The design of natural gas compressor with high compression rate was done and the subjects on the items used in design and their characteristics were handled. [2]. The study of design and development of high compressed gas compressor used in natural gas filling stations were done [3].

There are some dynamic tests in which air and natural gas was used as fluid in compressors. In this study, the changes of flow, heat and pressure were identified analytically and experimentally during compression [4]. Some researches on gas compressors with high pressure and screw. In the study, the pressure change in screwed compressors was shown in graphics according to the working conditions [5]. There is an

empirical study about the pressure distribution of high pressure compressors working. In the study, the pressure distributions of high pressured gas compressors with 5-stages on different working conditions were observed [5]. The performance of multiple stage high pressure compressors was increased. The cooling of fluid among stages and the behaviours of fluid in high pressures were researched [6]. Considering the compression of fluid on the level of high intensity in high pressure compressor, the behaviours of compressor equipment and their pressure characteristics were identified as numerical by finite element analysis [7]. The design was done by using 425 bar pressure and 50-160 0C gas heat range as the design conditions of high pressure gas compressor, and several test results done for 16 days were given [8].

B.The Comparison of CNG Compressors with Piston

In the experiments in this study, 3-4 stage compressors were used. The comparison of operating and the first investment cost of high pressure gas compressors with 3-4 stage has been given in Table 1. When Table 1 examined, the advantages and disadvantages of compressor in each number of stage can be clearly seen. Stage number can vary according to the usage aim and pressure. The varying stage number affects the energy cost. This situation is very important in terms of the organisation.

II. EXPERIMENTS

In this study, a cost study was done for 3-4 stage compressors used for the buses which have a tank with 1.176 m3 capacity and work with CNG. The parameters like heat, pressure and flow was observed during the period when pressures of 4 buses, which natural gas was filled in the CNG stations from two different regions of the city at the same time, reached the level of 200 bar. The view of the bus was given in Figure 2.

Compressors with different numbers of stage in the station filled the 4 buses at the same time. Stock pressures, bus's tank pressure and compressor input pressures can be measured during filling. In this study, energy costs was calculated in the light of different parameters. In Table 2, the beginning conditions of two different experimental study were given.

The compressor with 3 stage was used in the station where the input pressure is 12 bar, and the compressor with 4 stage was used in the station where the input pressure is 4 bar. The pressure of buses filled in this kind of tests is wanted not to be under 40 bar, but in this experimental study, the tank of 2 buses is under the value of 40 bar. In the experiments, the duration of their compensation with stock pressure was observed.

A. Experiment I

The pressure values in the tanks of buses filled with 3-stage compressors were given in Table 3. Tank stock volume of each bus is 1.176 m^3 . Totally filled volume is 4.704 m^3 . First, the pressures and stock pressures in the tanks were taken into the same level during gas filling. The reason for beginning the measurement value with 130 bar that the first pressures and stock pressures in the tanks are different from each other. After the compensation, bus and stock pressures increased together, and it was observed for every 10-bar pressure. It is necessary that the temperature of the gas filled shouldn't surpass 14 ºC. gas input temperature is 10 ºC in the study. The values for gas stock pressures and elapsed time during filling depending on time were given in Table 4.

B. Experiment II

The pressure values in the tanks of buses filled with 4-stage compressors were given in Table 5.

Because the tanks and stock pressures are different, the compensation was done in the value of 150 bar. The temperature of gas filled is 10ºC in the study. The values for gas stock pressures and elapsed time during filling depending on time were given in Table 6. As the compensation pressure began from 150 bar during the experiment 2, the number of measurements is 6.

III. RESULTS & EVALUATION

In both experiments, the elapsed time was measured until the tanks of buses reach the pressure value of 200 bar. In general, gas inputs and outputs aren't always equal to each other, but was the both experiments were done on the same day, the gas input and output temperatures were equal. In the 1st experiment, the pressure became 130 after 3,55 minute, and in the 2nd one, it became 150 bar after 3,06 minute. The time for every 10 bar pressure increase was observed.

The energy cost spent for the compensation time of 3-4-stage compressors was given in Table 7. The 3-stage compressor spent %21 more energy than the other until it reached the compensation pressure. 3-stage compressor was stabilized in the pressure of 130 bar, and 4-stage compressor was stabilized in the pressure of 150 bar. The energy spent for elapsed time, when 3-stage compressor reached to the pressure of 150 bar, is 2,60 $.

The energy cost spent during compression from 150 bar to 200 bar by compressors in the experiments was given in Table 8. 4-stage compressor spent %14 more energy than the other for reaching the value of 200 bar after the compensating pressure. The total energy spent during filling according to the number of compressors' stage was given in Table 9. The total energy spent during filling of 3-stage compressors is %23 more than the other. In the experiments, the busses' tanks filled by 3-stage compressors have 20-40 bar and the busses' tanks filled by 4-stage compressors have 60-90 bar. As the filling stations are in different regions, the pressure of network input is different as in Table 2. This situation affects both the

compensating pressure and the filling time.

IV. TABLES & FIGURES

Figure 1. Gas Compressors with High Pressures

Table 1. The comparison of Compressors with Varying Stages in Terms of Cost

The Advantages of 3-stage CNG Compressor	The Disadvantages of 3-stage CNG Compressor	The Advantages of 4-stage CNG Compressor	The Disadvantages of 4-stage CNG Compressor
The first investment cost is low because it rises into high pressures in lower stage	As cooling cost will increase because of high temperature on cylinder surfaces, operating cost will be more.	As gas heat will be low because of cylinder surface heat, there is a decrease in cooling cost.	Cylinder, piston and additional equipment will increase according to the stage number, the first investment cost is big.

Figure 2. The view of the buses

Table 2. The Conditions of Experimental Study

	Experiment I	Experiment II
The number of stage	3	4
Input Pressure (Bar)	12	4
Input Temperature (^{0}C)	10	10
Output Pressure (Bar)	225	225
Noise Level (dB)	75	80
Motor Power (kW)	355	355

Table 3. The Pressure Values in the Tanks of Buses

Buses	The pressures before filling	The pressures after filling
Bus 1	20 bar	200 bar
Bus 2	25 bar	200 bar
Bus 3	40 bar	200 bar
Bus 4	40 bar	200 bar

Table 4. Gas Stock Pressures During Filling Depending on Time

The Number of Measurements	Gas Stock Pressure [bar]	Elapsed Time [min.]
1st Measurement	130	3.55
2nd Measurement	140	5.23
3rd Measurement	150	6.35
4th Measurement	160	7.43
5th Measurement	170	8.45
6th Measurement	180	9.46
7th Measurement	190	10.43
8th Measurement	200	11.40

Table 5. The Pressure Values in the Tanks of Buses

Buses	The pressures before filling	The pressures after filling
Bus 5	90 bar	200 bar
Bus 6	80 bar	200 bar
Bus 7	60 bar	200 bar
Bus 8	90 bar	200 bar

Table 6. Gas Stock Pressures During Filling Depending on Time

The Number of Measurements	Gas Stock Pressure [bar]	Elapsed Time [min.]
1st Measurement	150	3.06
2nd Measurement	160	4.29
3rd Measurement	170	5.44
4th Measurement	180	6.50
5th Measurement	190	7.57
6th Measurement	200	9.00

Table 7. The Energy Spent Until Stabilization Time

3 –STAGE COMPRESSOR				4 –STAGE COMPRESSOR			
Stabilization Time [second]	Motor Power of Compressor [Kw]	Energy Spent Until Stabilization Time [Kwh]	Cost of Energy Spent[$]	Stabilization Time [second]	Motor Power of Compressor [Kw]	Energy Spent Until Stabilization Time [Kwh]	Cost of Energy Spent[$]
235	355	23.17	3.82	186	355	18.34	3.03

Table 8. Total Energies and Costs Spent Between 150-200 Bar

3 –STAGE COMPRESSOR				4 –STAGE COMPRESSOR			
Time Spent Between 150-200 Bar [Sec.]	Motor Power of The Compressor [Kw]	Energy Spent Between 150-200 Bar [Kwh]	Cost of Energy Spent[$]	Time Spent Between 150-200 Bar [Sec.]	Motor Power of Compressor [Kw]	Energy Spent Between 150-200 Bar [Kwh]	Cost of Energy Spent[$]
305	355	30.08	4.97	354	355	34.91	5.76

Table 9. Total Energy Cost

3 –STAGE COMPRESSOR					4 –STAGE COMPRESSOR			
Total Time [Sec.]	The Energy Spent Until Compensation time [Kwh]]	The Energy Spent Between 130-150 bar After Compensation [Kwh]	The Energy Spent between 150-200 Bar [Kwh]	The Cost of Total Energy Spent [$]	Total Time [Sec.]	The energy Spent until Compensation time [Kwh]	The Energy Spent between 150-200 Bar [Kwh]	The Cost of Total Energy Spent [$]
700	23.17	15.78	30.08	11.4	540	18.34	34.91	8.79

V. REFERENCES

[1] "What's New in Natural Gas Vehicles & Equipment", Pipeline & Gas Journal, Dec 1993,Vol 220, Issue 12, P53.

[2] Brezonick, Mike, "New High Capacity Natural Gas Compressor Package From Hurricane" Diesel Progress Engines & Drives, Oct 1995,Vol 61,Issue 10,P46

[3] Lochmann, K., Ziehe, G., "High-Pressure Compressor for CNG Filling Station: Development, Design, Application", Gaswarme İnternational,1998,47(4/5):267-271

[4] E. N. Vlasov, K. Mamaev, I. K. Shatalov, and E. V. Dedikov, "Improvıng Centrıfugal Superchargers in Compressor Statıons Ways of Acoustıcally", Chemical and Petroleum Engineering, Vol. 40, Nos. 1–2, 2004

[5] Koga, T., "High Pressure, High Standards: High Pressure Screw Gas Compressors", Hydrocarbon Engineering,2009,14(2):73-78

[6] Zheng XQ, Zhang YJ, Yang MY, "Research and Development on Transonic Compressor of High Pressure Ratio Turbocharger for Vehicle İnternal Combustion Engines", Science China-Technological Sciences, Jul 2010, 53,P1817-1823

[7] Kern,M.Horn,W.Hiller,S.J.,Staudacher, S., "Effect of Tip İnjection on the Performance of a Multi-Stage High-Pressure Compressor", Ceas Aeronautical Journal,2011,2(1- 4),99-110.

[8] Bidant, Y., Baumann, U., "Improving the Design of a High Pressure Casing with the Help of Finite Element Analysis to Ensure the Rotor Dynamic Stability of High Pressure Centrifugal Compressor Equipped with a Hole Pattern Seal", Journal of Engineering For Gas Turbines and Power-transactions of The Asme, Jul 2011,133.

[9] P. Droescher, M. Sattler, A. Laxander, "Dry Gas Seals For High-Pressure gas İnjection Compressors Used in High-Pressure Service for Gas İnjection" Pipeline and Gas Journal, 2011, 238,61-63

[10] Öztürk Tatar, "Three-Dimensional Numerical Study on Low-Speed Centrifugal Compressor" Master's Thesis, Institute of Science of the University of the Republic,,2005

[11] Yadullah BABAYEV, "A Compressor Body Powder Metallurgy and Diffusion of Manufacturing Resource Optimization applying methods", Dokuz Eylul University, Institute of Science, 2007

[12] Compressor Handbook, Editor Paul Hanlon, McGraw-Hill,2001

[13] Compressors, Prof. Dr. Kirkor YALÇIN, TMMO,2010