Optimization of Pipe Length Parameters, Number of Valves and Compressor Operations to Reduce Electricity Consumption

Achmad Nurhadi Arifin [1*], Indra Chandra Setiawan [2]
[1,2]*Program Studi Teknik Mesin, Universitas Pancasila, Jakarta, Indonesia*
* *Email Corresponding Author*: achmadnurhadisyauqi@gmail.com

ABSTRAK

Udara terkompresi adalah alat suplai energi yang sering digunakan dalam proses industri. Audit energi dan tindakan hemat energi hanya berfokus pada masalah teknis yang mempengaruhi efisiensi energi. Terkait masalah pengoperasian sistem udara bertekanan jarang ditangani terhadap efisiensi energi. Hanya 21% peserta dalam program audit energi Australia yang merekomendasikan tindakan hemat energi untuk sistem udara bertekanan. Konsumsi listrik paling besar di Pabrik otomotif yaitu pada mesin kompresor yang dibutuhkan untuk kebutuhan *pneumatic* mesin, *dies*, dan *jig* sehingga optimasi parameter panjang pipa, jumlah katup dan operasional kompresor untuk menurunkan konsumsi listrik sangat diperlukan. Metode penelitian menggunakan metode Taguchi serta di tinjau dengan pemantauan *Cumulative Sum Control Chart* (CUSUM) setelah melakukan eksperimen. Hasil eksperimen pada parameter panjang pipa 668 m, jumlah katup 6 pcs dan operasional kompresor 185 kW adalah parameter paling optimal untuk menurunkan konsumsi listrik 198.000 kWh/tahun dengan tekanan yang dihasilkan 5,43 bar dan penurunan tekanan 1,57 bar.

Kata kunci: Kompresor; Katup; Pipa bertekanan; Udara

ABSTRACT

Compressed air is a frequently used energy supply tool in industrial processes. Energy audits and energy-saving measures focus only on technical issues that affect energy efficiency. Related operating issues of compressed air systems are rarely addressed towards energy efficiency. Only 21% of participants in the Australian energy audit program recommended energy-saving measures for compressed air systems. The largest electricity consumption in an automotive factory is on the compressor engine which is needed for the pneumatic needs of machines, dies, and jigs so optimizing the parameters of pipe length, number of valves and compressor operation to reduce electricity consumption is needed. The research method uses the Taguchi method and is reviewed by monitoring the Cumulative Sum Control Chart (CUSUM) after conducting experiments. The experimental results on the parameters of pipe length 668 m, number of valves 6 pcs and operational compressor 185 kW are the most optimal parameters to reduce electricity consumption 198,000 kWh / year with the resulting pressure of 5.43 bar and a pressure drop of 1.57 bar.

Keywords: Compressors; Valves; Pressurised Pipework; Air

INTRODUCTION

Compressed air is an energy supply tool used in industrial processes. In the industrial sector, compressed air systems are one of the main energy consumers accounting for about 10% of the electricity consumed in the European Union and China, while in the US, Malaysia, and South Africa account for 9% of total energy consumption. However, abroad the energy efficiency (EE) measure that is quite well known is the pressurized air system (SUB). SUB efficiency improvement usually focuses on the supply side with the use of high-efficiency compressor motors, the introduction of variable speed drives, the application of automatic control systems, improving the dryer and air filter, compressor room temperature and etc. However, on the consumption side, compressed air distribution systems and consumer equipment also have a significant influence on the energy efficiency of the SUB. Energy audits and energy-saving measures focus on technical issues that affect energy efficiency (EE), while behavioral issues associated with the operation of SUBs are rarely addressed regardless of their effect on EE. The lack of energy efficiency programs for SUB has been highlighted. Specifically, only 21% of participants in the Australian energy audit program recommended energy-saving measures for SUB [1]. That is why SUB is very interesting to learn and research.

Compressors are inefficient and expensive compressed air producing devices that reach 30% to 70% of the cost of electricity production. This percentage is very influential but manufacturers are not inclined to save compressor and only focus on the SUB when it loses pressure which would affect the normal operation of manufacturing. This certainly has a great effect on EE SUB [1]. A compressor is a device used to increase the pressure of a compressed fluid [2]. The pressure decrease in the SUB pipe is influenced by the size of the cross-sectional dimensions of the pipe and the number of connections between the pipes. The research implies two compressor work optimizations, including: pipe dimension management and pressurized pipe installation replanning management [3], while the effect of downward pressure causes the company to bear operational costs of Rp. 5,760,451 / week. The research implies two compressor work optimizations, including: pipeline dimension management and operational cost management [4], then the gas flow speed in the pipeline is influenced by diameter, specific grafity, viscosity, distance and amount of gas flowed. The way to raise the pressure is installed by a compressor at a distance of 114 miles from Grissik Station. The installation of 2 compressors is installed in series with a capacity of 6070 HP and 8527 HP [5].

The demand for reducing electricity consumption costs for compressors requires appropriate process parameters to provide confidence that the products produced by the process meet the specified product quality standards. If costs are reduced and quality is maintained, the Company will get better value financial benefits and profits increase the morale of the workers. With various things in the background as discussed, the theme that will be the research material was chosen, namely the optimization of pipe length parameters, the number of valves and compressor operations to reduce electricity consumption.

Electricity consumption budget in one of the automotive companies in Indonesia. This explains the electricity budget in 1 in 2023. In the middle of the year, there was a revision of the budget to the initial budget.

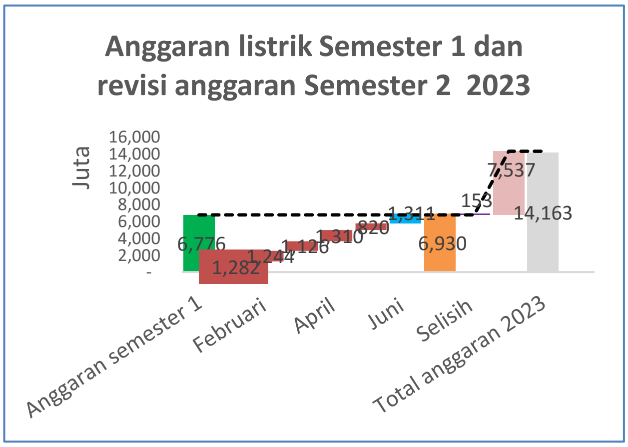

Figure 1. Electricity Consumption Budget Chart in 2023.

Automotive manufacturers based on Figure 1. provides a budget of Rp. 14,162,000,000 for electricity consumption. The largest electricity consumption is in the compressor engine needed for pneumatic engines, dies, and jigs so that the compressor utility must be lowered. If the cost of electricity, especially compressor engines, can be reduced automatically, the automotive manufacturer gets an increase in profits every year.

The researcher will create a pressurized air system (SUB) as follows:

- Compressor performance monitoring that was initially manual has become digital so that monitoring can be timed per day at a low cost.
- Optimization of 5 compressor units with different power and different locations as well.
- Modify long and complicated pipelines in a simple and low-cost way.

So that with the need to reduce compressor electricity consumption and demand for quality that remains guaranteed, this study has the following objectives:

- It can guarantee a reduction in electricity consumption, compressors can meet energy savings in 2023 at factories related to reducing electrical energy.
- Determine the optimal process parameter value so that it can be run on compressor machine operations easily and keep the pressure still within the factory standard.
- The target is to reduce costs by 16.7% compared to previous electricity consumption by optimizing the value of the specified parameters.

RESEARCH METHODS

The stages of this research are based on a flow chart as shown in Figure 2.

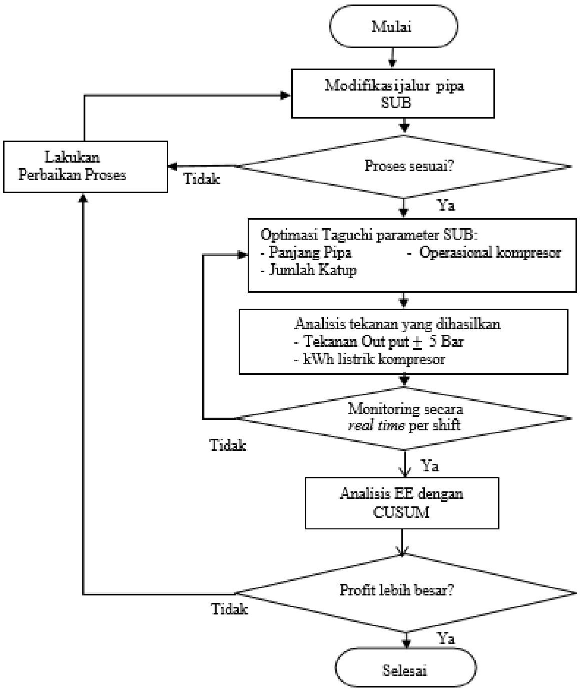

Figure 2. Research Flow Diagram

Research Stages

Parameter Determination

After pipe modifications are carried out with the installation of valves in several pipes, further research is carried out to determine the parameters of pipe length, number of valves, compressor operation. This is done to ensure that the improvements made can be accounted for from the aspect of control over the efficiency performance of the compressed air system (SUB). To determine the optimal parameters, the Taguchi experimental method is used. The parameters can be seen in Table 1.

Table 1. SUB Parameters On Research

Kontrol parameter	Level	
	1	2
A - Panjang pipa, (m)	668	854
B - Jumlah Katup, (pcs)	6	0
C - Operasional kompresor, (kW)	185	222

The explanation of the parameters in Table 1. related level 2 is illustrated as Figure 3.

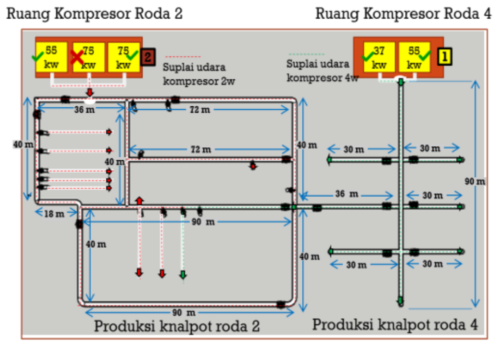

Figure 3. Illustration Level 2 (Compressor Operation 222 kW)

Figure 3. for the length of the pipe if it is summed up as a whole, which is 854 m, for the valve as a barrier between the pipes 0 pcs, while the compressor operation with a mark (√) is 55, 75, 37, 55 so that the total compressor operation is 222 kW. Level 1 is illustrated as Figure 4.

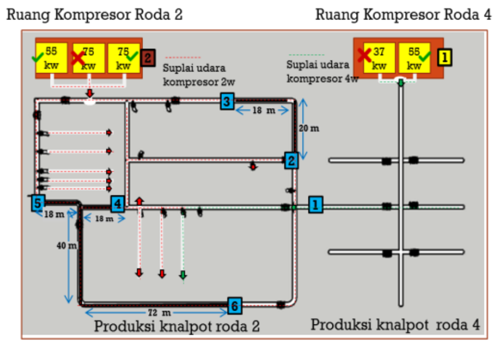

Figure 4. Level 1 Illustration (185 kW Compressor Operation)

Figure 4. for the length of the pipe, if it is summed up as a whole, it is 854 m minus the number of pipes closed by valves no. 2, 3, 4, and 5 so that the length of the pipe becomes 668 m for the valve as a barrier between the pipes of 6 pcs, while the operation of the compressor with a mark (√) is 55, 75, 55, so that the total compressor operation is 185 kW.

RESULTS AND DISCUSSION

Pressure Experiment Results (P2)

The P2 pressure table above is graphed which can be seen in Figure 5.

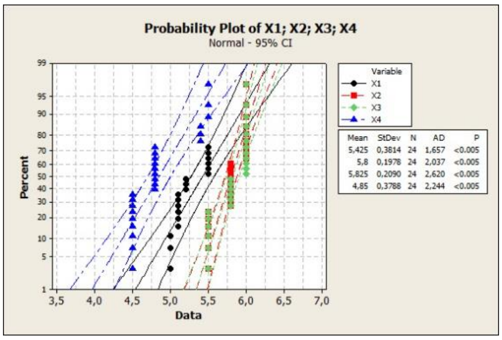

Figure 5. Probality P_2 Chart

As seen from Figure 5. experiments X1, X2, X3, X4 are still in the standard production area pressure, which is 4 – 6 bar and the optimal P2 pressure is 5 Bar. For the p value of all experiments <0.005, it shows that there is a statistically significant difference.

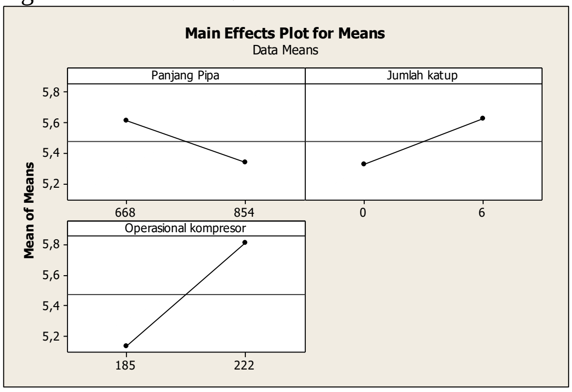

Figure 6. P_2 Mean Chart

Figure 6. Explaining that the one that has the greatest influence on the average pressure result is the compressor factor with a delta of 0.675, the second valve with a delta of 0.300 and the third length of the pipe with a delta of 0.275.

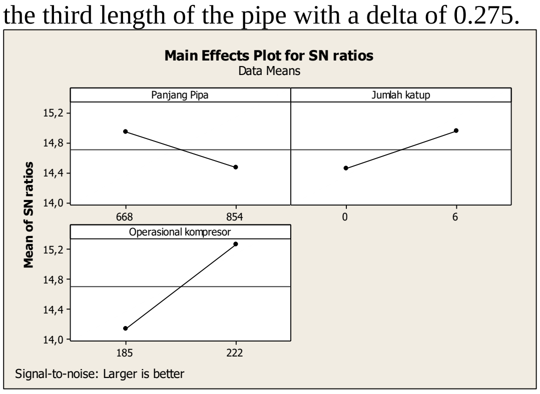

Figure 7. SNR P_2 Chart

Figure 7. has the characteristics of The bigger the better with the best SNR, which is the compressor factor with a delta of 1.14, the second best valve with a delta of 0.51 and the 3rd best with a delta of 0.47. A good SNR position is found in the X3 experiment with a pipe length of 668 pcs, valve installation of 6 pcs, and compressor operation of 222 kW with an average pressure of 5.82 bar while the factory's needs have an optimal value of 5 bar so it needs to be included in the control map graph seen in Figure 8.

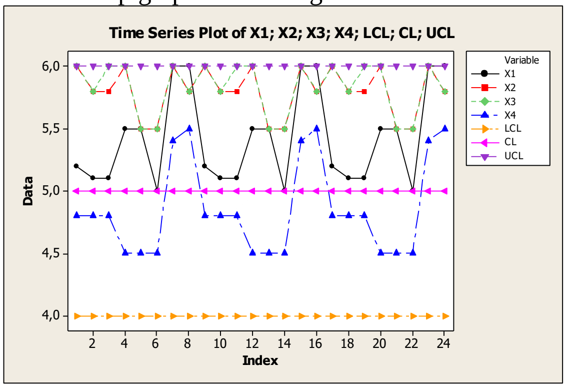

Figure 8. Pressurized Air System (SUB) Control Map

X1 experimental data with an average P2 of 5.45 bar has an optimal value close to 5 Bar so that with a pipe length of 668 m, the number of valves 6 pcs, and an operational compressor of 185 kW is recommended to be run in the SUB factory.

Results of the Pressure Reduction Experiment (Δp)

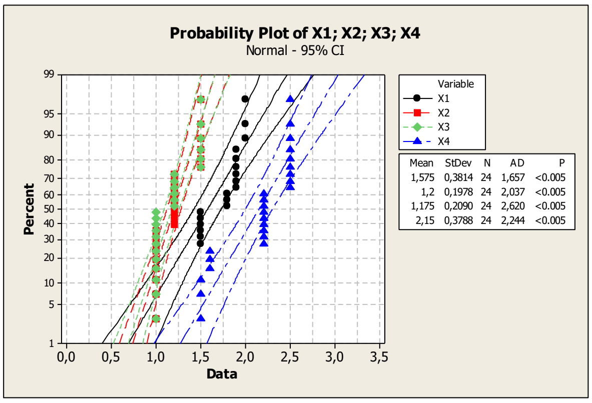

Figure 9. Probality Δp Chart

It can be seen from Figure 4.5 that experiments X1, X2, X3, X4 for the p value of all experiments <0.005 shows that there is a statistically significant difference.

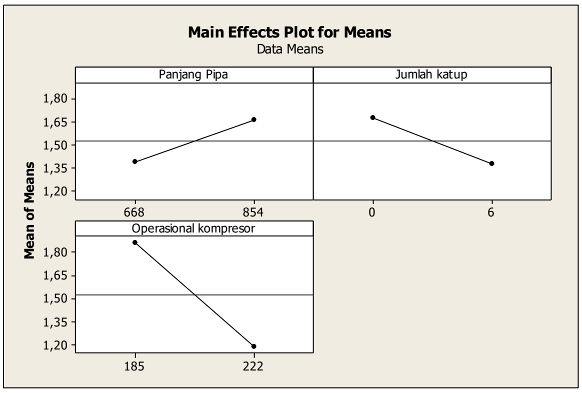

Figure 10. Pressure Drop Mean Chart (Δp)

Figure 10. Explaining that the ones that have the greatest influence on the average result of pressure reduction are the compressor factor with a delta of 0.675, the second valve with a delta of 0.300 and the third pipe length with a delta of 0.275.

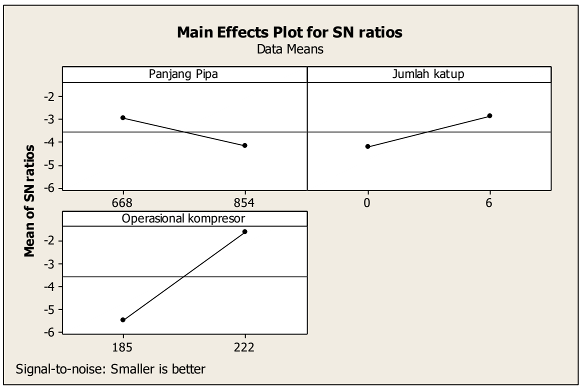

Figure 11. Pressure Drop SNR Chart (Δp)

Figure 11. has the characteristics of The smaller the better with the best SNR which is the compressor factor with a delta of 3.867, the second best valve with a delta of 1.379 and the 3rd best with a delta of 1.214. The best SNR position or has the smallest value is found in the X3 experiment with a pressure drop (Δp) of 1.17 bar at a pipe length factor of 668 m, the number of valves 6 pcs, and an operational 222 kW. The rule is that the bigger the SNR, the smaller the loss. To avoid large losses due to excessive pressure drops, it can be done by adjusting the operational parameters of the compressor.

Results of Compressor Electricity Consumption Experiment (kWh)

After the hourly data is known, the electricity consumption data will be presented every 10 minutes so that the graph shown in Figure 12 appears.

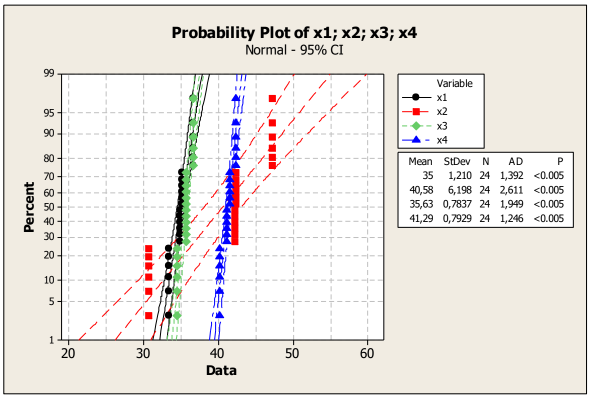

Figure 12. Electricity kWh Probality Graph

It can be seen from Figure 4.8 that the experiments X1, X2, X3, X4 for the p value of all experiments <0.005 show that there is a statistically significant difference.

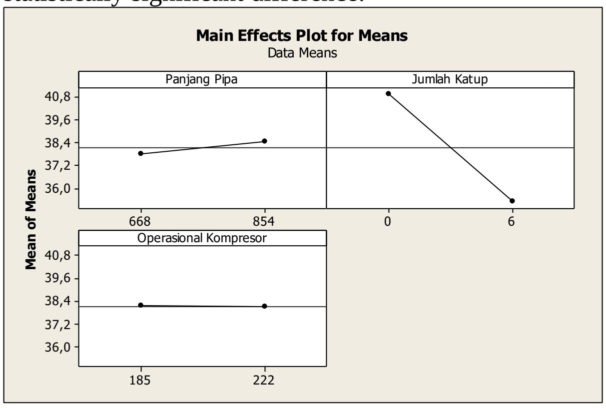

Figure 13 Graph of Mean Electricity Consumption Every 10 Minutes (kW)

Figure 4.9 explains that the one that has the greatest influence on the average result of electricity consumption is the factor of the number of valves with a delta of 5.62, the second length of the pipe with a delta of 0.67 and the third operation of the compressor with a delta of 0.04.

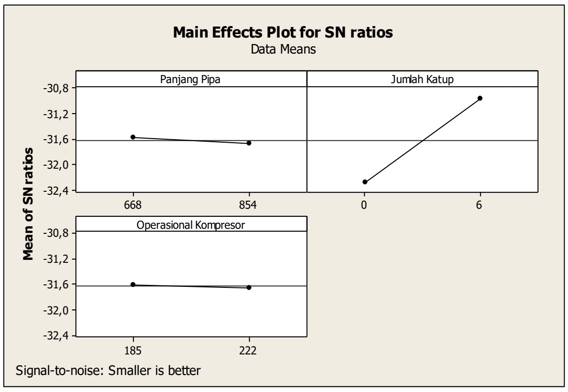

Figure 14. Electricity Consumption SNR Graph Every 10 Minutes (kW)

Figure 14. has the characteristics of The smaller the better with the best SNR i.e. the number of valves with a delta of 1.33, the second best pipe length with a delta of 0.10 and the best to 3 operational compressors with a delta of 0.05. The best SNR position or has the smallest value is found in the X1 experiment with 10 minutes of electricity consumption of 35 kW at a pipe length factor of 668 m, the number of valves 6 pcs, and an operational 185 kW. The rule is that the bigger the SNR, the smaller the loss. With the change in compressor electricity consumption above, it can be calculated that the amount of electricity consumption produced every 10 minutes which was previously 41.29 kW became electricity consumption after it was 35 kW. If calculated per hour before 263 kWh while the electricity consumption after is 213 kWh So that every day there is a change in electricity consumption from the previous 3950 kWh to 3200 kWh or there is a decrease in electricity consumption of approximately 19%.

Determining the Optimal Parameters

The length of the pipe from the regression equation calculation has a significant effect on electricity consumption. This is in accordance with experiment 1, which has the smallest littric consumption, so it is necessary to study the effect on the pressure produced in the production area. Here is Table 2. which explains the weight of the experiment.

Table 2. Experimental Stage

Eksperimen	Rank P_2	Rank Δp	Rank kWh	Rank P_2	Rank Δp	Rank kWh	Total %	Rank Eksperimen
X1	1	3	1	40%	20%	40%	100%	1
X2	2	2	3	30%	30%	20%	80%	3
X3	3	1	2	20%	40%	30%	90%	2
X4	4	4	4	10%	10%	10%	30%	4

Experiment X1 is the smallest compressor electricity consumption of the other 3 experiments, besides that the pressure produced is still within the standard, which is 5.43 bar or closest to the midline, which is 5 bar.

Timely monitoring of the compressor's electricity consumption to produce compressed air after experiments is essential. Figure 15. is a graph about timely monitoring of CUSUM.

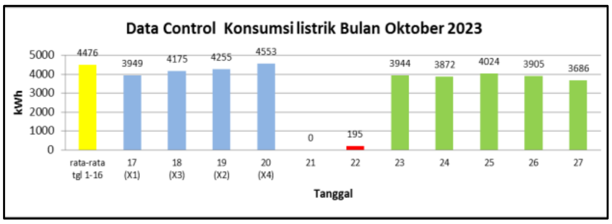

Figure 15. Timely CUSUM Monitor Chart

From the comparison of the graph in Figure 4.11 it can be seen that:

1. Days 1 - 16 are CUSUM monitoring before there is Optimization
2. On the 17th - 20th is the CUSUM monitoring experiment
3. The 23rd - 27th is the CUSUM monitoring after optimization
4. CUSUM monitoring obtained:
5. The results of the X1 experiment on the 17th consumed 3949 kWh of electricity
6. The results of the X2 experiment on the 19th consumed 4255 kWh of electricity.
7. The results of the X3 experiment on the 18th consumed 4175 kWh of electricity.
8. The results of the X3 experiment on the 20th consumed 4553 kWh of electricity.

The X1 experiment on October 17, 2023 was the most optimal experiment in achieving electricity consumption than the X2, X3 and X4 experiments with a result of 3949 kWh.

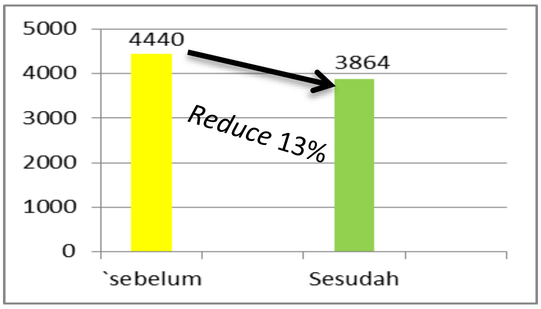

Figure 16.. Before and After Charts Monitor CUSUM in Time

The results of CUSUM's monitoring can be seen in Figure 16 that the average electricity consumption of the compressor before was 4440 kWh while the graph after was 3864 kWh. This was observed to reduce the compressor's electricity consumption by 13%.

Profit Calculation

After making improvements in each company, of course, it will evaluate related to the calculation of profits. The calculation of profits can be started in Table 3.

Table 3. Comparison of kWh of Electricity Before With After

Item	Before (kWh)	After (kWh)

2-wheel and 4-wheel compressors	263	213

Table 3. It is a comparison of the power consumption of the compressor before and after the optimization of pipes, valves and compressor operations so that the calculation of energy savings is as follows:

a. Energy saving for 1 hour
   = 263 kW - 213 kW = 50 kW
b. Energy saving for 1 month, 15 hours of power per day and 22 working days in 1 month of operation
   = 50 x 15 x 22 = 16,500 kWh
c. Investment Cost Rp. 150,000,000
d. One of the automotive companies is a private electricity company customer with a high voltage (TT) power of 2,050 kVA, with a Basic Electricity Tariff (TDL) price of Rp 1986.5/kWh so that in total it is added to the load cost to be Rp 2,288.9/kWh. So that it can be calculated that the electricity savings fund used per month is 16,500 kWh per month multiplied by Rp2,288.9/kWh. The energy saving costs if the pipeline, valve, and compressor operational length optimization project are as follows:

   C_{month} = Rp 37.781.700

   C_{year} = Rp 453.380.400

In this analysis it is used to determine whether the investment of the project is financially viable. The following are the results of the calculation of each parameter from the method used in the feasibility analysis of the investment plan for the optimization of pipeline, valve, and compressor operational length optimization projects:

Table 4. Project Investment Feasibility Parameters

No.	Eligibility Parameters	Value
1.	*Net Present Value* (NPV)	Rp 280.711.380
2.	*Internal Rate of Return* (IRR)	5,4%
3.	*Benefit Cost Ratio* (BCR)	2.87
4.	*Payback Period* (PP)	0,33

When viewed from the eligibility parameters in Table 4. used that the Net Present Value (NPV) assuming a 1-year service life of IDR 280,711,380 and greater than zero, the value of the Internal Rate of Return (IRR) of 5.4% which is greater than the interest rate used, which is 5%, the value of the Benefit Cost Ratio (BCR) of 2.87 which is more than 1, then the investment of the project is considered feasible and profitable for the company in the future, and the Payback Period (PP) for this project is 0.33 years, meaning that the investment cost can be returned in less than 1 year, thus it can be concluded that the project is feasible from an economic aspect.

CONCLUSION

The research carried out can be taken several things which are conclusions as follows:

1. SUB research by modifying pipes can reduce compressor electricity consumption by 198,000 kWh/year with a pressure generated of 5.43 bar and a pressure drop of 1.57 bar.
2. The parameters of pipe length 668 m, the number of valves 6 pcs and the operation of the compressor 185 kW are the most optimal parameters to reduce electricity consumption.
3. SUB optimization reduced electricity consumption from Rp. 2,294,160,000 for a year to Rp. 1,858,560,000 so that costs decreased by 19% and exceeded the initial target of 16.7% with a Payback Period (PP) for this project of 0.33 years.

BIBLIOGRAPHY

[1] C. Eras, A. Sagastume, V. Sousa, J. Jos, M. Javier, and C. Ulloa, "*Energy management of compressed air systems . Assessing the production and use of compressed air in industry*," vol. 213, 2020, doi: 10.1016/*j.energy*.2020.118662.

[2] H. T. Sularso, Pompa dan Kompresor, 7th ed. Jakarta: Pradnya Paramita, 2000.

[3] D. Ismail, "Analisis Penurunan Tekanan Aliran Udara Pada Pipa Bertekanan," vol. V, no. 2, pp. 13–21, 2019.

[4] A. M. Ilham Arif Firmansah, "ISSN: 2745-6331 (*online*) page 173-190," Anal. penurunan Sist. kompresor pada pembangkit PT. Indocement Tunggal Prakarsa, vol. 3, no. 2, pp. 173–190, 2021.

[5] R. A. Asyari, "Pemodelan Penentuan Lokasi Stasiun Kompresor Untuk Pipa Transmisi Gas Dari Sumatera Selatan – Jawa Barat," vol. 2, no. 1, pp. 43–53, 2018.

[6] B. Triatmodjo, “Hidraulika 1,” Jakarta: Beta Offset, 1996, p. 220.

[7] M. Carello, A. Ivanov, and L. Mazza, “*Pressure drop in pipe lines for compressed air: Comparison between experimental and theoretical analysis*,” *Adv. Fluid Mech.*, vol. 21, pp. 35–44, 1998.

[8] I.Soejanto, Desain Eksperimen Dengan Metode Taguchi, 1st ed. Yogyakarta: Graha Ilmu, 2009.

[9] W. Ruslan, “Ekonomi Teknik Bunga Uang dengan Pemajemukannya,” *Ekon. Tek.*, vol. 1, 2016.

[10] M. Benedetti, F. Bonfà, V. Introna, A. Santolamazza, and S. Ubertini, “*Real time energy performance control for industrial compressed air systems: Methodology and applications* ,” *Energies*, vol. 12, no. 20, 2019, doi: 10.3390/en12203935.

[11] Hendri, “Potensi penghematan energi pada kompresor di PT. ABC,” Potensi penghematan energi pada kompresor di PT. ABC, vol. IX, no. 1, pp. 72–82, 2014.

[12] J. Q. Hwang and H. A. Samat, “*Maintenance for Energy efficiency* : *A Review Maintenance for Energy efficiency : A Review*,” 2019, doi: 10.1088/1757-899X/530/1/012047.

[13] A. Indra and A. Nursyamsu, “Analisa Aliran Fluida Dalam Pipa Spiral Pada Variasi Pitch Dengan Menggunakan Metode *Computational Fluid Dinamics* (CFD),” pp. 1–15.

[14] I. Jorge and M. Diaz, “*Energy savings measures in compressed air systems*,” 2020, doi: 10.32479/ijeep.9059.This.

[15] N. L. R. Sertyanto, Teori dan Aplikasi Desain Eksperimen Taguchi, 1st ed. Malang: UB Press, 2017.