Cost Reduction through Maintenance of Compressed Air System in Pulp & Paper Industry

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ABSTRACT

The pulp and paper industry is an energy-intensive process industry where energy contributes about 16-20% of the total manufacturing cost. Due to shortage in energy availability and increase in energy cost, energy conservation has become a necessity in the paper industry. Consequently, any process that significantly decreases the energy requirement in the pulp and paper process will have a significant beneficial effect on the overall energy input. It was observed that a significant saving can be done if the losses of compressed air due to leakage are limited to 5% of the total capacity of air compressor through maintenance. It is found that losses due to leakage in lubricating air compressors in Star Paper Mills Limited, Saharanpur (India) were 28.18% when zero load tests were conducted. Due to which, a financial loss was assessed to approximately Rs744245.44. The present study aims at maintenance practices of air compressors in pulp and paper industry in order to minimize air leakage to 10.5% by taking various measures. The maintenance practices of air compressors adopted to minimize air leakage are proved to minimize a financial loss of Rs. 464490.88per annum.

Key words: Air compressor, load test, zero load tests, air leakage, cost saving

Introduction

The pulp and paper industry is an energy-intensive process industry where energy contributes 16-20% of the manufacturing cost[1]. Due to shortage in energy availability and increase in energy cost, energy conservation has become a necessity in the paper industry. Consequently, any process that significantly decreases the energy requirement in the pulp and paper process will have a significant beneficial effect on the overall energy input. Daniel presents the development of a knowledge-based system for the evaluation of industrial equipment in terms of preventive maintenance criticality. A deterministic rating methodology based on the principles of reliability centered maintenance constitutes the logic of the analytical model of the system[2]. Present study aims at minimizing air leakages in air compressor system and to check the efficiency of air compresses. Keeping this in view, load and zero load brake horse power of air compressor, the capacity of compressor using pump up time test to check the condition of the compressor, the load test for the entire plant to determine the actual air consumption at different time intervals and the total quantity of air being lost due to leakages were calculated.

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Experimental work

Cost reduction studies through maintenance of the compressed air system were conducted at Star Paper Mills Ltd., Saharanpur located in the foothills of Shivalik hills of Northern India. Brake horse power (BHP) of the air compressors was calculated at load and zero load basis[3]. The pump up time test[4] was conducted for measuring the output of the air compressor at constant speed and discharge pressure and the total time to increase the pressure from 2 to 81 psi of a receiver of given volume was noted. Load testing of air compressors for entire plant was conducted to determine consumption of compressed air at different time intervals in a day. The specifications of the air compressors (low pressure lubricated system) selected for cost reduction studies through maintenance are: make - Ingersoll-rand, model - ESH-1-lubricating, theoretical capacity 557.15 feet^3/min (cfm), motor horse power 100, RPM 400 and water cooling. The total air leakages of compressors at zero load (no compressed air is being used for actual work of the plant) were calculated. Then, the various maintenance steps were taken to bring the air leakages in the limit of permissible losses i.e. less than 5%. The maintenance steps taken to minimize air leakages are: inspection and repacking of stem packing of every valve in the system, checking of all gasket joints of flanges and replacing gas kits whenever necessary, repairing/ replacing leaked shut off valves and tightening of all flanges. Then, total air leakages of compressors at zero load (no air is being used for actual work) were again calculated.

A. Calculation of Brake Horse Power

The brake horse power of air compressors was calculated based on load and zero load basis by using following formula:

Power output (HP)

$$= \frac{1.73 \times I \times V \times PF \times \eta_m}{746} \text{ ----------(1)}$$

Where: V= voltage, I= current (amp), P.F= power factor, η_m = motor efficiency (%)

For the calculation of BHP, theoretical power factor of the motor at full load 0.79 and at zero loads 0.6 is measured. The efficiency of motor is assumed to be 88%. At load condition current is 100 and at zero load 50 amp and voltage 400 V.

Compressor-1

At load

$$= \frac{1.73 \times 100 \times 400 \times 0.79 \times 0.88}{746} = 64.49 \text{ BHP-- (2)}$$

Zero load

$$= \frac{1.73 \times 50 \times 400 \times 0.60 \times 0.88}{746} = 24.49 \text{ BHP---(3)}$$

Compressor2

At load
$= \frac{1.73 \times 100 \times 400 \times 0.79 \times 0.88}{746} = 64.49$ BHP-- (4)

Zero load
$= \frac{1.73 \times 50 \times 400 \times 0.60 \times 0.88}{746} = 24.49$ BHP----- (5)

B. Capacity calculation of compressor using Pump up time test

The actual capacity of air compressor was determined by pump up time test. The following formula was used to determine the time required to pump up the receiver:

Actual free air delivery, feet^3/min

$$= \frac{(P_2 - P_1) \times CFT}{P_{atm} \times t.} \text{ ---------- (6)}$$

Where: t = Time taken to pump up the receiver in minutes

P_2 = Final pressure (psi) in receiver

P_1 = Initial pressure (psi) in receiver

CFT = Cubic feet content of the air receiver and the intermediate volume between the compressor discharge and receiver inlet

P_{atm} = Atmospheric pressure

Pump up Test time for air compressor no.1

Theoretical capacity of compressor (AD) = 557.15 feet^3/min.
Swept volume of compressor (PD) = 776.01 feet^3/min

P_1 = 2 psi
P_2 = 81 psi
t = 2.82 min.
Receiver volume = 214.75 feet^3
Pipe line volume = 13.89 feet^3
After cooler volume = 0.37 feet^3
Total volume = 229.01 feet^3

Therefore, actual free air delivery, feet^3/min

$$= \frac{(81 - 2) \times 229.01}{13.41 \times 2.82} = 478.41 \text{ ---------- (7)}$$

The reduction in the capacity of air compressor

$$= \frac{557.15 - 478.41}{557.15} \times 100 = 14.13\ \% \text{ ---- (8)}$$

Theoretical volumetric efficiency of compressor

$$= \frac{AD \times 100}{PD} = \frac{557.15 \times 100}{776.01} = 71.8\% \text{--- (9)}$$

Where: AD = Actual free air delivery (theoretical)

PD = Piston displacement

Actual volumetric efficiency of compressor

$$= \frac{478.41 \times 100}{776.01} = 61.64\% \text{ ---------- (10)}$$

Where: AD = Actual free air delivery (calculated)

PD = Piston displacement

The actual volumetric efficiency of air compressor is 10.16% less than that theoretical volumetric efficiency of compressor. Therefore, compressor needs maintenance.

Pump up Test time for air compressor no. 2

Theoretical capacity of compressor (AD) = 557.15 feet^3/min.
Swept volume of compressor (PD) = 776.01 feet^3/min

P_1 = 4 psi
P_2 = 77.5 psi
t = 2.44 min.
Receiver volume = 214.75 feet^3
Pipe line volume = 12.72 feet^3
After cooler volume = 0.37 feet^3
Total volume = 227.84 feet^3

Therefore, actual free air delivery, feet^3/min

$$= \frac{(77.5 - 4) \times 227.84}{13.41 \times 2.44} = 511.8 \text{ ------- (11)}$$

The reduction in the capacity of air compressor

$$= \frac{557.15 - 511.8 \times 100}{557.15} = 8.14\% \text{---- (12)}$$

Theoretical volumetric efficiency of compressor

$$= \frac{AD \times 100}{PD} = \frac{557.15 \times 100}{776.01} = 71.8 \text{ -- (13)}$$

Where: AD = Actual free air delivery (theoretical)

PD = Piston displacement

Actual volumetric efficiency of compressor

$$= \frac{511.8 \times 100}{776.01} = 65.95\% \text{ ----------(14)}$$

Where: AD = Actual free air delivery (calculated)

PD = Piston displacement

The actual volumetric efficiency of air compressor is 5.85% less than that theoretical volumetric efficiency of compressor. Therefore, compressor needs maintenance.

Load Test

Load test was conducted at different time intervals in a day and the amount of air consumed in the plant was determined. The amount of air consumed during load and zero loads was determined.

Load test for air compressor 1 and 2

Both the air compressors are operated to generate air to fulfill the air requirement of the plant for duration of 1 hour. The air generated by compressor1 at full load between 9.00

Table-1 Load test of Compressor-2

Sl. No.	Particulars	Operated time, min	% operated time	Air supplied
1	Full load	3.23	5.38	511.8x 3.23= 1653.11 feet^3 = 27.55 feet^3/min
2	No load	56.77	94.62	Nil

Table-2 Load tests for air Compressor-1and2 at different time intervals

Sl. No.	Load test at different time intervals	Air supplied, feet^3/min
1	8.30-9.30 AM	438.00
2	10.35-11.35 AM	691.40
3	11.40-12.40 AM	387.00
4	12.45-1.45 PM	471.83
5	2.30-3.30 PM	478.41
6	3.40-4.40 PM	505.96
7	5.00-6.00 PM	518.05
Average		498.66
Standard deviation		88.52

to 10.00 A.M. is 478.41 feet^3/min (4). Air compressor2 generates air 27.55 feet^3/min for 3.23 min only as per requirement of the plant and it remains under zero load condition for 56.77 min for a total period of 1 hour. Therefore, total air used = 478.11+27.55 = 505.96 feet^3/min--(15) Similarly, load test for compressor1 and 2 carried at different time intervals in a day is depicted in Table 2.

Table 2 indicates that the maximum load of 691.40 feet^3/min was observed between 10.35 to 11.35 AM which indicates that compressed air was used for other cleaning and maintenance work. The minimum load of 387.00 feet^3/min was observed between 11.40 to 12.40 PM. The average plant load for low pressure lubricated system is evaluated approximately 498.66 feet^3/min.

C. Cost of air generation at load

During conduction of pump up test one compressor consumes 100 amp at load whereas, 50 amps during zero load.

The brake horse power of compressor is 64.49 at pressure 5.62 kg/cm^2.

The average load of both the compressors is 498.66 feet^3/min (during load tests)

Total output of both the compressor for 24 hours

= 498.66 x 24 x 60 = 718070.4 feet^3

Total power consumption for 498.66 feet^3/min at 5.62 kg/cm^2

= 64.49 x 0.746 x 24 = 1154 kWh.

Total cost in rupee = 1254 x 4.00 = Rs 5016.00 (One unit = Rs. 4.00)

Therefore cost for 1000 feet^3 of air

$$= \frac{5016 \times 1000}{718070.4} = \text{Rs. } 6.99$$

The actual cost of compressed air includes:

a) Repair = 15%
b) Operating charges = 20%
c) Power = 65%

Keeping the above parameter in view, the cost of 1000 feet^3 compressed air will be

$$= \frac{6.99 \times 100}{65} = \text{Rs. } 10.75$$

(a) Total air generated by both the compressors at load in a day

= 498.66x60x24=718070.4 feet^3

Air generation cost/day

$$= \frac{718070.4 \times 10.75}{1000} = \text{Rs. } 7719.25$$

Air generation cost per annum

= 7719.25 x 30 x 12 = Rs 2778932.45 ---(16)

D. Cost of air at zero Load condition

Both the compressors operate at zero load 48.61% (average) of the time in a day

Total time at zero load in a day = 11.66 hours.

Total power consumed by both the compressor at zero load = 23.93 HP.

= 23.93 x 0.746 x 11.66 = 208.15 Kwh

= 208.15 kWh x 4.00 = Rs. 832.60 per day = 832.60x30x12 = Rs. 299736 per annum---------- (17)

Therefore, total air generation cost = Total cost at load + Total cost at zero load = Rs 2778932.45 + Rs. 299736.00 = Rs. 3078668.45 per annum

Leakage test at zero load

One air compressor is operated for leakage test at zero load for 15 min only. The compressor was on load for a period of 4.12 min out of 15 min at different time intervals but no air was utilized at that time for performing actual work. It means that total quantity of air generated during 4.12 min was lost due to leakage.

Table-3 Leakage test at zero load

Sl. No.	Particulars	Operated time, min	% operated time	Air supplied
1	Full load	4.12	27.46	511.8x 4.12= 2108.61 feet^3 = 140.57 feet^3/min
2	No load	10.88	72.54	Nil

% of air leaked = 28.18%

Loss due to air leakage

The air leakages = 140.57 feet^3/min

Permissible limits for air leakages = 7.02 feet^3/min (5% of total plant load)

Excess air leakages = 133.55 feet^3/min

Therefore air loss due to leakage/day

= 133.55 x 24 x60

= 192312 feet^3/day

$$= \frac{192312 \times 10.75}{1000} = \text{Rs. } 2067.35$$

= Rs. 2067.35x 30 x 12 = Rs744245.44 per annum

The air leakages in compressor are more than industrial norms for air leakage. Therefore, maintenance of compressor system is essentially required. The maintenance work at stem packing of every valve in the system and repack where ever necessary, checking of all gasket/ joints of flanges and replacement of gas kits whenevernecessary,repairing/replacing of leaked shut off valves and tightening of all flanges was carried out and then leakage test at zero load was conducted.

Leakage test at zero load after maintenance of compressor lines

In the similar way, one air compressor is operated for leakage test at zero load for 15 min only. The compressor was on load for a period of 1.54 min out of 15 min at different time intervals but no air was utilized at that time for performing actual work. It means that total quantity of air generated during 1.54 min was lost due to leakage.

% of air leaked

$$= \frac{52.84 \times 100}{498.66} = 10.5\%$$

Loss due to air leakage

The air leakages = 52.84 feet^3/min

Permissible limits for air leakages = 2.64 feet^3/min (5% of total plant load)

Table-4 Leakage test at zero load

Sl. No.	Particulars	Operated time, min	% time	Air supplied
1	Full load	1.54	10.26	511.8x 1.54= 788.17 feet^3 = 52.84 feet^3/min
2	No load	13.06	89.74	Nil

% leakage		% saving	Saving in Rs
Before maintenance	After maintenance		
28.18	10.5	17.68	Rs744245.44 — Rs. 279754.56 = Rs. 464490.88

Excess air leakages = 50.2 feet^3/min
Therefore air loss due to leakage/day
= 50.2 x 24 x60
= 72288.0 feet^3/day
= $\frac{72288.0 \times 10.75}{1000}$ = Rs. 777.10
= Rs. 777.10x 30 x 12 = Rs. 279754.56 per annum

Conclusions

It can be calculated that the general maintenance of the lubricating compressor is to be done periodically otherwise the capacity of compressors will be affected. No load test of lubricating compressor indicates that the air leakage was about 28.18% which is much higher compared to industrial norms. The air leakages may result a financial loss of Rs. 279754.56 per annum. The air leakages were reduced to 10.5% by taking various maintenance steps the financial loss of Rs. 464490.88per annum is mitigated.

References

1. Dutt Dharm, Upadhyaya J.S., Tyagi C.H. and Ahamad S. (2007). A practical approach towards energy conservation through bio-refining of mixed krafts pulps, 3rd International Bioenergy Conference and Exhibition held at Jyväskylä (Finland), (2007) 667-672.
2. Daniel J. Fonseca. (2000). A knowledge-based system for preventive maintenance, Expert Systems 17 (5), 241247.
3. Vincet Del Tow (1982). Sinusoidal steady-state response of circuits, In: Principles of Electric Engineering, Prentice Hall of India Pvt Ltd., Conaught Circus, New Delhi, pp175.
4. S. Dom Kundwar (1999). Reciprocating Air Compressor, In: Thermal Engineering, Dhanpat Rai &Co (P) Ptd., Nai Sarak, Delhi, pp25.5