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100 # Air Centrifugal or Reciprocating

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100# AIR...CENTRIFUGAL OR RECIPROCATING ?

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INTRODUCTION

The purpose of this evaluation is to compare the design and operating features of centrifugal and reciprocating 100 psig discharge air compressors. There will be locations and operating conditions where one or the other will be the better buy for the specific customer. A customer who purchases a compressor in the HP sizes from about 300 HP and above for 100# air service will probably be looking at the alternates of either reciprocating or centrifugal compressors. The most important consideration in each application is what is the most economical purchase for each application.

In the following pages you will find a comparison between two types of compressors. From the information presented and with a thorough knowledge of the economic considerations for a specific job, an evaluation can be made between centrifugal and reciprocating compressors.

Keep in mind while reading the following evaluation that each application should be judged on the following merits.

A need for compressed air which is a utility requirement for a customer and this utility should be supplied by means that will be the most economical for a specific application. The following considerations should be included in the evaluation:

- First Costs
- Operating Costs (power & water)
- Installed Costs
- Maintenance Costs
- Tax Write-off and Depreciation
- Reliability
- Existing Standby Machines
- Regulation
- Delivery Requirements
- Power Factor Penalty

FIRST COST

Reciprocating Compressors above 300 HP selections usually include synchronous motor driven units with static exciters. Centrifugal units are induction motor driven and thus to be comparable installations, the induction motor should include capacitors for power factor correction. The power factor can be corrected to about 0.95 lagging by adding capacitors, but a synchronous motor drive can provide .8 leading or 1.0 power factor motors, therefore, this item would be comparable but not equal. Each application should be evaluated with respect to existing power factor penalty and the result of adding either an induction or synchronous motor. This can be done by the local power company.

Items like expansion joints on most centrifugal compressors suction and discharge connections are required to maintain alignment and eliminate stress on the machine. A centrifugal also requires other items as shown in Checklist #I to make a complete installation. These items are not required by a reciprocating compressor.

Air receivers are required by most industrial air systems to enable the compressors to keep up with peak and/or sudden demand periods without reducing plant air pressure. Centrifugal compressors do not require air receivers for regulation purposes but most plants do need air receivers to maintain air pressure during peak demand periods.

You should realize that the induction motor usually supplied with a centrifugal may require a reduced voltage starter, whereas a synchronous motor will probably only need a full voltage starter at a considerable cost savings. This is because a synchronous motor inrush starting current is approximately 350% of full load current, whereas, an induction motor draws approximately 550 - 600% of full load current.

Each evaluation should include all equipment required to make a complete installation. The following check list will help compare equipment:

Check List I.
Accessories Required for Complete Installation

	Recip.	Cent.
Compressor	X	X
Motor	X	X
Static Exciter	X	
Lube Oil System	X	X
Intercooler	X	X
Coupling		X
Baseplate		X
Inlet filter-silencer	X	X
Air Receiver	X	X
Motor Starter (AAL for recip. vs. maybe a reduced voltage for centrifugal)	X	X
Automatic Protection System	X	X
Aftercooler	X	X
Surge Control		X
Suction Throttle Valve		X
Anti-Surge Valve		X
Blow-Off Silencer		X
Discharge Line Check Valve		X
Vibration Switches		X
Expansion Joints on Air Discharge		
Power Factor Correction Capacitors		X

INSTALLED COSTS

Usually the total installed cost for either a centrifugal or reciprocating type will be about the same. The main difference will be the extra cost for foundation for a reciprocating compressor; however, the extra amount of concrete will usually be small and the centrifugal unit will probably cost more to install electrical wiring (larger wire may be required due to higher inrush current) and to install blow-off silencer pressure piping not required by the reciprocating type.

The following installed cost check list will give a means of evaluating all installed costs for a centrifugal vs. a reciprocating compressor.

Check List II.
Consider all Installation Costs

	Recip.	Cent.
Build Foundation	X	X
Mount Compr. on Foundation	X	X
Align driver & compressor		X
Wire Lube Oil Pump (or pipe air motor)	X	X
Wire Drive Motor	X	X
Wire & Install Starter	X	X
Install Inlet straightening vanes (or long radius elbow)		X*
Install Expansion Joints		X*
Install Aftercooler & Piping	X	X
Connect & Calibrate Anti-Surge Control		X
Install Blow-off Silencer and Piping		X
Install Power Factor Correction Capacitors		X
Install Air Receiver	X	X
Install Air Filter Silencer	X	X

(* Only on some units)

POWER COST

Effect of Ambient Conditions - Centrifugal Compared to Reciprocating Compressors: The theoretical power to compress a gas can be expressed either as a function of volume flow and pressure rise or as a function of weight flow and head. The equations are equivalent but the first equation works better with a displacement compressor while the second is better with a centrifugal compressor.

A centrifugal compressor design point represents a requirement for head. The designer estimates the efficiency and then provides a work input to the gas (ft.-lb./lb.) which, when multiplied by the efficiency, will product the required head.

The work input is transferred to the gas in the impeller when the impeller transfers angular momentum to the gas.

The point of all this is that once the impeller is designed and a speed set, the energy that a pound of gas will absorb in passing through the impeller is established. This is true despite variations in inlet temperature, pressure level, throttling, etc.

If the work input is fixed and the head requirement drops (as it does in the winter) this excess head can either be throttled out in a suction throttle valve or the machine can be operated out on the curve at a higher flow. In either case the energy consumed per pound of flow will remain essentially constant.

A centrifugal compressor, therefore, will deliver a pound of air with a constant expenditure of energy, winter or summer. A reciprocating compressor, reacting as it does to inlet volume flow, will deliver substantially increased weight flow with the same power consumption when the inlet density increases in the winter. These factors result in an energy cost per pound of air approximately as shown in Figure #1.

The BHP per 100 cfm of a centrifugal compressor will increase as the intake air temperatures drop. This generally varies as a ratio of the absolute intake design temperature over the absolute intake temperature at a given time (winter or summer).

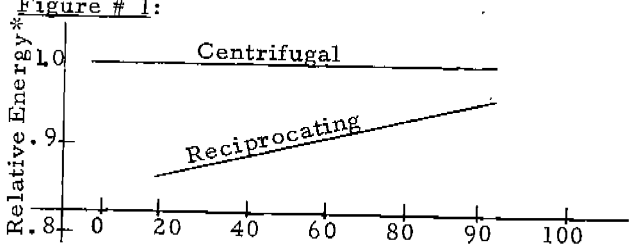
For Example: If the design BHP per 100 cfm of a centrifugal compressor is 21.0 at 90°F intake temperature, determine the BHP per 100 cfm at 20°F.

$$\frac{(90+460)}{(20+460)} \times 21.0 = 24.3 \text{ BHP per 100 cfm at } 20^{\circ}\text{F}$$

This is a 15.7 % increase in power.

The reciprocating compressor will increase in BHP/100 cfm as a result of imperfect intercooling.

It is possible to throttle a centrifugal during cold temperature seasons to reduce horsepower and weight flow, but the reciprocating compressor can also be regulated and the difference in BHP/100 will hold true as can be seen in the following Figure # 1:



(*per pound of air req'd)

Power costs are calculated from the following formula:

$$\frac{\text{Power Cost}}{\text{Year}} = \text{Bhp} \times \text{cfm of compressor} \times .746 \frac{\text{Kw}}{\text{Bhp}} \times \text{Power cost} \frac{\$}{\text{kwh}} \times \frac{1}{\text{motor effcy.}} \times \frac{\text{\#hr. oprtn.}}{\text{Year}}$$

It is important when using this formula that the Bhp and cfm numbers for both types of compressors be calculated for the average design operating point of intake air and water temperature and percent load of the compressor.

For every 10° of imperfect intercooling in a reciprocating compressor the Bhp/100 cfm is increased by 1%. Most reciprocating compressor intercoolers are designed to have a 20 degree cold temperature difference. To obtain perfect intercooling the cooling water temperature to the intercooler must be 20 degrees F below the air intake temperature to the first stage cylinder. Average ambient air temperatures are important in evaluating various types of compressors.

Normal 24 hours per day average ambient temperatures for numerous cities around the country are shown from data obtained from the U.S. Weather Bureau in Appendix I. The cooler the average air intake temperature, the more savings with a reciprocating compressor.

The following is an example of the power savings that can be obtained by using a reciprocating compressor at an average installation:

Operating Conditions:
3200 CFM FULL LOAD
7000 Hours PER YEAR
50°F Mean Average Ambient
3¢/KwH POWER COST
2.25 less bhp/100 cfm
(Required for the reciprocating unit)

Result: $11,000 savings per year in power cost.

Electric Power costs have increased in the past several years as a result of the oil crisis and increased electrical power requirements. Future power costs will probably increase at an even faster rate. Therefore, a total evaluation should include a factor for projected future power costs.

CONSIDER COOLING WATER COSTS

Reciprocating units will require 2 to 2-1/2gpm of cooling water per 100 cfm for the compressor. Cooling water requirements for centrifugal units will vary with manufacturer and size of unit. Most will require 4 to 4-1/2 gpm of cooling water per 100 cfm for the compressor. Both centrifugal and reciprocating compressor after-coolers will require 1.5 gpm per 100 cfm.

Industrial costs for cooling water will vary, depending on the source of water, and how a company charges off the costs of water piping, pumps, cooling towers, maintenance, etc. A common figure for a large plant seems to be about 20¢ per 1000 gal. This figure like power costs is increasing each year.

Cooling water costs can be calculated by the following formula:

$$\frac{\text{gpm}}{\text{100cu. ft.}} \times \text{CFM} \times \frac{\text{60min}}{\text{hr.}} \times \frac{\text{\# hours}}{\text{Year}} \times \frac{\$ \text{ cost of water}}{\text{1000 gal.}} = \text{Cooling Water Cost}$$

Example: 5000 cfm, 100 psig, water cost $.20 per 1000 gal. Centrifugal compressor water required 4 gpm/

100 cfm. The difference in water consumption 2 gal/100 cfm

$$2 \text{ gpm}/100 \text{ cu.ft.} \times \frac{60 \text{ min}}{\text{hr.}} \times \frac{7000 \text{ hrs.}}{\text{Years}} \times \frac{\$.20}{1000\text{gal.}} \times 5000 \text{ cfm}$$

= $8,400 per year savings by a Reciprocating Compressor.

MAINTENANCE

Some centrifugal manufacturers proclaim "no maintenance" as the advantage for this design. My experience shows that a centrifugal compressor may run for extended periods of time without maintenance. However, maintenance when necessary can be serious, and require expensive parts replacement usually with factory servicement to supervise the job (at customer's plant or at the factory).

The centrifugal, particularly at high impeller speeds of 20,000 to 50,000 rpm and above, is subject to damage through erosion due to dirty intake air or moisture carrying through the intercooler. This can result in unbalance and vibration leading to bearing, seal, and gear tooth wear. The entire compressor and drive may be affected. Control, regulation, and lubrication are complex system which also must be cared for.

A reciprocating compressor will require routine preventive programs to inspect valves and piston rings for wear and replacement as necessary. Parts are inexpensive, available and usually stocked by customer or compressor manufacturer warehouse. Parts can be replaced by regular mechanics usually without special supervision. Regulation is simple and reliable.

A tabulation of an estimate of the time required to do various maintenance functions for centrifugal and reciprocating compressor - shown in Appendix II. You will note that the simple inspection each shift that only takes 1/4 of an hour per shift will be the largest total maintenance cost. Example: a plant operating 3 shifts, 300 days per year will require (300 x 3 x 1/4 +225 hours per year in total labor for once a shift inspection only.) The most expensive maintenance function is the routine shift inspection regardless of the type of unit.

Intake air filters and oil filters require cleaning regularly. Intercooler bundles are subject to material buildup from untreated water, in both reciprocating and centrifugal compressors. Safety shutdown switches must be checked out regularly.

The total cost of spare parts over a five to eight year period will also be very close for an average installation. In general, the total overall average maintenance cost of centrifugal and reciprocating machines will be equal.

The following is a summary of the spare part replacement to be expected from a well-maintained centrifugal and reciprocating compressor.

Part Requirements - Centrifugal:
Estimate - will require after five years:
- Complete set high speed bearings
- (2) complete set seal rings
- Complete set low speed bearings
- Complete set of impellers
- Intercooler bundles
- (5) sets of oil filter cartridges
- (5) sets of air filter elements
- Overhaul of lube oil pump(probably new seals)
- (5) Complete gasket sets

Part Requirements - Reciprocating:
Estimate - will require after five years:
- (2) sets of Valve Parts
  (1) set HP & LP Packing & OilScraper
  5 to 10 sets of Valve Seat Gaskets
  5 to 10 sets of Valve Cover Gaskets
  Est. 5 Oil Filter Cartridges
  Est. 5 Air Filter Elements
  One Complete Gasket Set

REGULATION

The most efficient operating load for either type of compressor will be full load operation. However, most industrial plants will not require full capacity from their compressors at all times and therefore efficient regulation is important.

Most reciprocating compressors will be equipped with five step control which will enable the unit to operate at full load, three quarter load - 1/2 - quarter load - or no load. The horsepower requirement for the reciprocating unit will vary from 100% at full load to 10% at no load.

Centrifugal compressors will regulate the amount of air delivered from the compressor, depending on plant operating requirements, efficiently down to the point the centrifugal will go into surge. A comparison of centrifugal and reciprocating compressor throttle ranges or stability ranges is shown on Curve # I in Appendix # III.

Several points should be noted from Curve I:
1. The reciprocating compressor is best for large savings in load requirements.
2. The 4-stage backward leaning compressor

has a longer regulation range than a radial bladed centrifugal.

3. The reciprocating compressor has a greater stability range.

Curve # II (also shown in Appendix III), shows the relative differences in horsepower required for two types of centrifugal compressor designs compared to that of a reciprocating design. The comparison shows the design point of a centrifugal compressor. At lower than 95°F intake air temperatures, the savings in horsepower by the reciprocating unit will be even greater as explained in the previous section POWER COST.

CONCLUSION

The major economic considerations that should effect a total evaluation of centrifugal and reciprocating compressors have been presented in this article to show most of the design differences, thus cost differences, between the two types.

A hard and fast rule cannot be established to guide the evaluating engineers to conclude that the best selection between a given horsepower range should either be a reciprocating unit or a centrifugal unit because of the many variables involved. The major evaluation variables that will change any evaluation will be 1) Initial Cost and 2) Cost of Power and Water, and 3) the total number of hours of Operation.

With all of the variables defined then the best economic selection can be made with simple calculations.

In today's energy economy, the value of efficient machines can be evaluated and can result in major ownership value to a user - with increases in energy cost, the value of efficient machines will even be more valuable.

The reciprocating compressor is a good example of a study in the life cycle of a product. During the past 15 years other types of compressors have been developed that could be manufactured for far less cost than the reciprocating types. Because of low utility cost, the major factor in purchasing much machinery-like compressors has been low cost.

Because the new designs were manufactured at low cost, the reciprocating compressor lost part of its appeal during the late '60's. However, with the value of electrical energy and water costs changing for a lower or static level each year to a time when utility costs are increasing each year, reciprocating compressors have obtained a greater ownership value than ever before.

APPENDIX I

City	State	Average Ambient °F
Montgomery	Alabama	65
Anchorage	Alaska	35
Phoenix	Arizona	69
Fort Smith	Arkansas	62
Los Angeles	California	62
San Francisco	California	57
Denver	Colorado	50
Hartford	Connecticut	50
Wilmington	Delaware	54
Miami	Florida	75
Idaho Falls	Idaho	42
Chicago	Illinois	51
South Bend	Indiana	50
Des Moines	Iowa	49
Wichita	Kansas	57
Louisville	Kentucky	56
New Orleans	Louisiana	54
Portland	Maine	45
Baltimore	Maryland	56
Boston	Massachusetts	51
Detroit	Michigan	62
Jackson	Mississippi	66
Kansas City	Missouri	57
Billings	Montana	48
Omaha	Nebraska	52
Reno	Nevada	48
Concord	New Hampshire	46
Newark	New Jersey	55
Albuquerque	New Mexico	57
New York City	New York	55
Charlotte	North Carolina	61
Bismarck	North Dakota	42
Cleveland	Ohio	49
Tulsa	Oklahoma	60
Portland	Oregon	54
Pittsburgh	Pennsylvania	52
Charleston	North Carolina	65
Rapid City	South Dakota	47
Nashville	Tennessee	60
Dallas	Texas	66
Houston	Texas	70
Salt Lake City	Utah	51
Richmond	Virginia	58
Seattle	Washington	51
Milwaukee	Wisconsin	45
Casper	Wyoming	46

APPENDIX II

MAINTENANCE COSTS

CONSIDER MAINTENANCE COSTS

(Recommended Routine Maintenance)

		Man-Hours		
		Recip.		Cent.
Item	Frequency	2000 to 3200 CFM	4200 to 6400 CFM	
Check crankcase oil level & add oil	Once-a-Shift	1/4	1/4	1/4
Clean all air intake & discharge valves	Semi-Annually	20	40	--
Check Cond. of cylinder bore thru valve opening	Semi-Annually	(Included in same time as valves are cleaned)		--
Check effectiveness of lubrication of cyl. bore & valves	Semi-Annually	20	40	--
Clean impellers	Annually	--	--	16
Check cond. of water side of coolers & jackets, acid clean	Annually	16	18	16
Tighten all bolts & nuts	Annually	4	6	4
Change crankcase oil & clean or replace filter	Annually	8	12	16
Check clearances in all bearings (at time of oil change)	Every 3 Years	4	8	6
Inspect piston rod packing & scraper rings	Annually	1	2	--
Clean or replace shaft seals	Annually	--	--	6
Check piston (or wheel) clearances	Annually	4	8	8
Adjust crosshead (or speed increaser)*	Every 5 Years	16	42	16
Clean control air filter & regulator	Semi-Annually	1	1	--
Clean Motor	Annually	16	16	16
Clean air intake filter	Semi-Annually	4	4	4
Check safety shutdown switches	Annually	6	6	6

APPENDIX III