# Centrifugal Compressors and HOC Dryers

## Reduce Energy Costs by $2.8 million

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### Project Overview

This chemical plant spent an estimated $3,153,022 annually on energy (steam and electricity) to operate the compressed air system at their facility. The plant staff established their energy costs as 5.3 cents per kWh and $9.00 /1,000 lbs of steam per hour. The set of projects implemented in this system assessment reduced energy costs by an estimated $2,841,946 or 88% of current use. In addition, these projects reduce demand on the boiler systems and add reliability and back-up to the compressed air system. The capital investment for completing the projects totalled $1,782,400, providing a simple payback period of 8 months.

This was a demand-side and supply-side system assessment. Due to article-length constraints, this article will discuss the supply-side optimization part of the project. This is where the majority of the energy-savings were realized. The first significant supply-side projects was to replace the existing air compressors, one of which was using a steam turbine, with new electric-driven air compressors. The second significant supply-side project was to replace the externally-heated blower-purge compressed air dryers with heat-of-compression compressed air dryers.

**TABLE 1: TOTAL PROJECT SUMMARY**

| PROJECT | SAVINGS PROFILE | ENERGY AND OTHER SAVINGS | | | TOTAL PROJECT COST ($) |
|---|---|---|---|---|---|
| | | AVG KW | KWH | SAVINGS ($) | |
| SUPPLY-SIDE SYSTEM | | | | | |
| 1. Replace existing steam-driven and electric air compressors with two new electric-driven units | Boiler energy-use savings by eliminating steam | 54 | 473,040 kWh + 100% of Steam Use | $2,390,271 | $1,358,000 |
| 2. Replace existing dryers with heat-of-compression (HOC) desiccant dryers | Eliminate dryer blowers and heaters | 871 | 7,629,960 | $404,327 | $423,000 |
| DEMAND-SIDE SYSTEM | | | | | |
| 3. Several Demand Reduction Projects | 806 cfm | 102 | 878,979 | $47,348 | $25,000 |
| **TOTAL** | **806 scfm** | **1,027 kW** | **8,981,979 kWh** | **$2,841,946 per year** | **$1,782,400** |

### The Centrifugal Air Compressors

Compressed air is supplied by three centrifugal air compressors using Inlet Butterfly Valves. The load profile, or air demand, of these three units is relatively stable during all shifts. The average actual air flow, supplied to the plant, is 5,132 scfm. Air compressor units #1 and #2 are operating at 67% and 47% of full flow capacity while unit #3 is running at 95% of full flow capacity. Average outlet air pressure is 110 psig and the plant is running 8,760 hours per year.

Annual plant energy costs related to the air compressors, were $2,748,695 per year. These estimates are based upon a blended electric rate of $0.053 /kWh.

Air compressor unit #1 is a steam-driven turbine that consumes 30,000 lbs of steam per hour — according to plant personnel. The average cost for this 600 psi steam is $9.00 per 1,000 pounds per hour. The total energy costs to operate this unit is 9 x 30 or $270 per hour x 8,760 hrs or $2,365,200 per year. The main objective of the project is to eliminate the use of steam as a power source and to replace the current compressors with new efficient units.

The project installed three new electric-driven, three-stage, centrifugal compressors: one 700 hp units in the South Plant and one 500 hp unit in the North Plant. The units are water-cooled.

The two most common control methods used for centrifugal compressors are **modulation** and **blow off.** Modulation is relatively efficient at very high loads but is usually limited to a total turndown of 10-40%. (This can vary dramatically among various compressor models.) After "modulation" or "turn-down", the compressor will just "blow off" excess air. The basic power draw at the blow-off point will stay the same regardless of the load. The existing system has inlet butterfly valve control with blow off.

There are modern electronic control systems today that can be applied which will close off the inlet and idle the unit more efficiently. This approach can significantly reduce the unit's kW draw. Inlet guide vanes can also increase the efficiency of the turn down (about equal to full load efficiency) but they will not extend it. The new units take advantage of both of these features.

The new units deploy Inlet Guide Vanes (IGV) to allow them to turn-down efficiently under partial load conditions. The main idea, however, is to have the 700 horsepower unit running at close to full load where it can deliver a specific power ratio of 6 scfm per kW. The 500 horsepower compressor will run at roughly 57% load and deliver a specific power of 5.74 scfm per kW. This will represent a significant improvement in specific power over the existing electric air compressors that are delivering 5.22 and 5.02 scfm per kW due to their older design, inlet butterfly valves, pressure requirements, and load conditions.

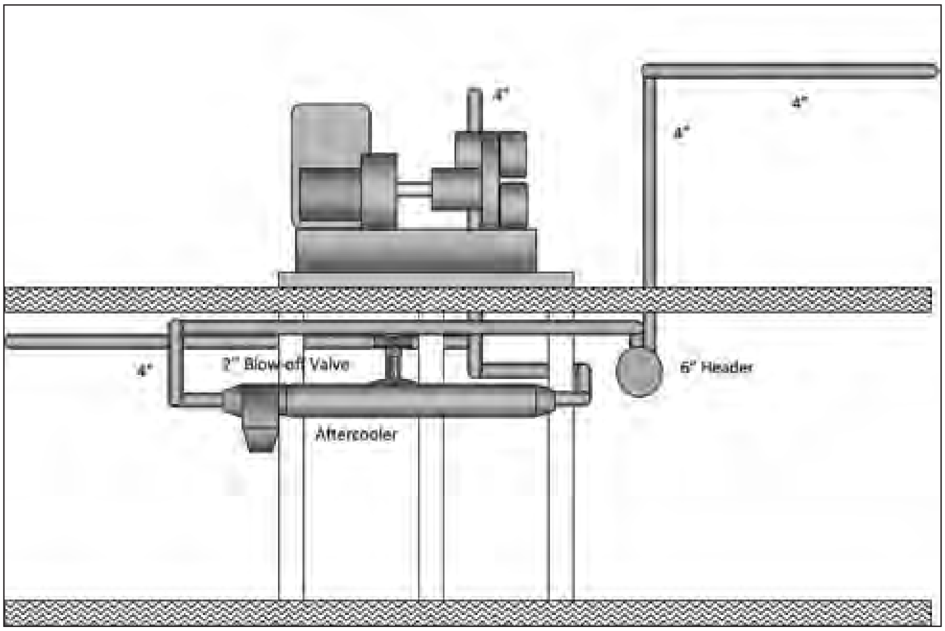


*Figure 1. Steam-Turbine Centrifugal Air Compressor with 2" Blow-off Valve*

# CENTRIFUGAL COMPRESSORS AND HOC DRYERS REDUCE ENERGY COSTS BY $2.8 MILLION

| TABLE 2: COMPRESSOR USE PROFILE – CURRENT SYSTEM | | | | | | | |
|---|---|---|---|---|---|---|---|
| UNIT # | COMPRESSOR DESCRIPTION | FULL LOAD | | ACTUAL ELEC DEMAND | | ACTUAL AIR FLOW | |
| | | DEMAND (KW) | AIR FLOW (SCFM) | % OF FULL KW | ACTUAL KW | % OF FULL FLOW | ACTUAL |
| Production Shift: Operating at 110 psig discharge pressure for 8,760 hours | | | | | | | |
| 1 | Steam Turbine | NA | 2,825 | — | — | 67% | 1,890 |
| 2 | Electric Centrifugal | 541 | 2,825 | 80.8% | 437 | 47% | 1,328 |
| 3 | Electric Centrifugal | 401 | 2,015 | 97% | 389 | 95% | 1,914* |
| | | | **TOTAL (Actual):** | | **826 kW** | | **5,132** |

| TABLE 3: COMPRESSOR USE PROFILE – NEW SYSTEM | | | | | | | |
|---|---|---|---|---|---|---|---|
| UNIT # | COMPRESSOR: MANUFACTURER/MODEL | FULL LOAD | | ACTUAL ELEC DEMAND | | ACTUAL AIR FLOW | |
| | | DEMAND (KW) | AIR FLOW () | % OF FULL KW | ACTUAL KW | % OF FULL FLOW | ACTUAL SCFM |
| Production: Operating at 100 psig discharge pressure for 8,760 hours | | | | | | | |
| 1 | New 700 hp | 541 | 3,244 | 94% | 510 | 94% | 3,059 |
| 2 | New 500 hp | 387 | 2,223 | 67.7% | 262 | 57% | 1,267 |
| | | | **TOTAL (Actual):** | | **772 kW** | | **4,326 cfm** |

| TABLE 4: SUMMARY OF KEY COMPRESSED AIR SYSTEM PARAMETERS AND PROJECTED SAVINGS | | |
|---|---|---|
| SYSTEM COMPARISON | CURRENT SYSTEM | NEW COMPRESSORS AND LOWER DEMAND |
| Average Flow (cfm) | 5,132 cfm | 4,326 cfm |
| Compressor Discharge Pressure (psig) | 110 psig | 100 psig |
| Average System Pressure (psig) | 105 psig | 95 psig |
| **Electric and Steam Cost per cfm** | **$535.59 /cfm/yr** | **$82.83 /cfm/yr** |

## Optimizing the Compressed Air Drying System

### South Plant

There are two externally-heated blower-purge desiccant compressed air dryers. Unit #2 has an electric heater and Unit #1 dryer has a steam regeneration heater.

Dryer Unit #2 has a 15 hp blower and a 75 kW heater, while Unit #1 dryer uses 130 psi steam for heat. Plant personnel calculate the energy cost of the 130 psi steam cost at $9.00 /1,000 lbs steam/hr. We estimate that this dryer uses 6,000 lbs/hr to operate at 75% of the time.

There are some operational issues with Unit #1 dryer in the blower system. During our site visit, the safety relief valve was being opened several times per minute. Plant personnel believe this is caused by the 4-way valves that are leaking past, allowing high pressure air into this system. There is also a pressure control valve which is not closing and causing a significant amount of compressed air to escape. This valve is connected to a 1" metal pipe that vents to the atmosphere and along with this, a manual valve with a 1/4" stainless steel tube exhausting air.

| TABLE 5: ENERGY COST COMPARISON OF DESICCANT AIR DRYERS: | | | | | |
|---|---|---|---|---|---|
| MANUFACTURER | EXISTING UNIT #1 | EXISTING UNIT #2 | EXISTING UNIT #3 | PROPOSED UNIT #1 | PROPOSED UNIT #2 |
| UNIT TYPE | EXTERNAL HEAT (STEAM REGEN) | EXTERNAL HEAT (ELEC REGEN) | EXTERNAL HEAT (BLOWER REG) | HEAT-OF-COMPRESSION | HEAT-OF-COMPRESSION |
| Rated Flow @ 100 ºF / 100 psig / 100 scfm | 3,000 | 3,000 | 2,000 | 3,000-cfm class** | 2,500-cfm class** |
| Purge air scfm | 0 | 0 | 0 | 0 | 0 |
| Full Load Heater kW | NA | 75 | 50 | 0 | 0 |
| Full Load Blower kW | 13 | 13 | 7.46 | 0 | 0 |
| Total Full Load kW / 1,000 lbs steam/hr | 13/6 | 88 | 57.46 | 0 | 0 |
| 8-hour Cycle Time | 9.75 (blower @ 100) | 56.25 (blower @ 13) | 37.5 (blower @ 10) | 0 | 0 |
| Net Electric Demand (kW) | 9.75 | 69.25 | 44.96 | 0 | 0 |
| **Total Annual Operating Cost ($)** | **$359,306** | **$27,298** | **$17,723** | **0** | **0** |

* Based upon a blended electric rate of $0.053 per kWh and operation of 8,760 hours per year.

**Specific size of dryer should be selected in cooperation with OEM.

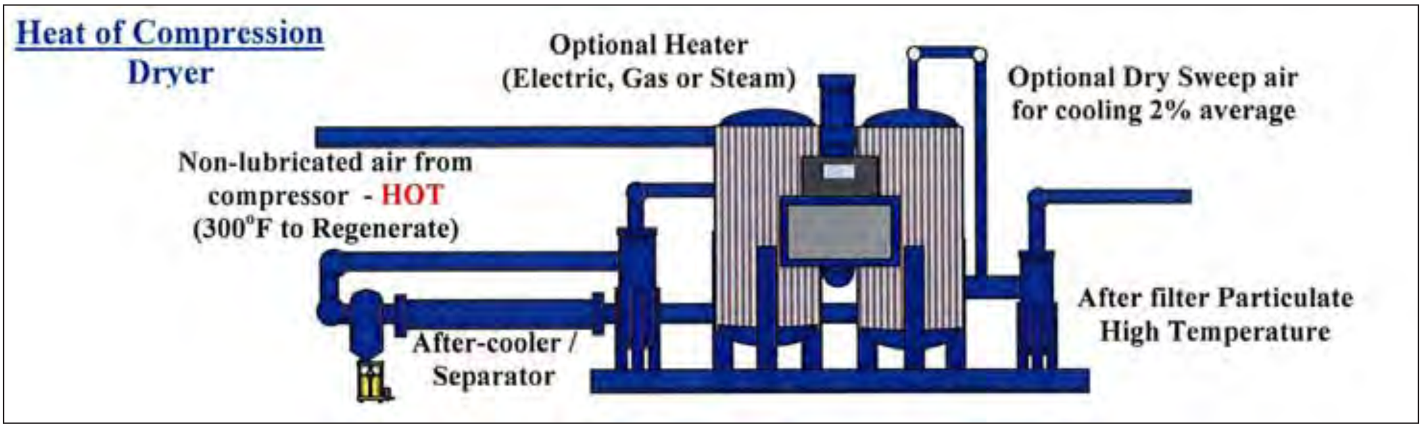


*Figure 5. Typical Heat-of-Compression Layout*

We estimated the air loss through the 1" pipe to be 100 cfm, while the 1/4" stainless tube to exhaust air loss to be 50 cfm. This issue of over-pressurizing the blower system not only wastes air, but could raise a safety issue. These air losses are listed in the Demand-Side of the System Assessment.

### North Plant

The North Plant operates an externally-heated blower-purge desiccant compressed air dryer (Unit #3). It appears to be operating correctly. According to information provided by plant personnel who track and log historical data in the computer system, the North Plant's dryer does have a history of performing well (dew point) and is the most consistent of all three dryers.

### Theory of Operation of the Heat-of-Compression Dryer

The system assessment recommended the installation of two new heat-of-compression (HOC) compressed air dryers to accompany the new compressors. They replaced all three of the existing external steam and heat-regenerated desiccant air dryers in the South and North Plants. The air compressors and dryers can be bought as a package unit due to special piping requirements of HOC systems. The unique design of HOC dryers capitalizes on the "free heat" generated by the oil-free centrifugal air compressor. The annual energy savings, related to compressed air drying, will be $404,327.

Compressed air enters the dryer directly from the second stage of the compressor.

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| TABLE 6: ENERGY SAVINGS AND PROJECT COSTS | | | | |
|---|---|---|---|---|
| **AIR SYSTEM COMPONENT** | **CURRENT ANNUAL ELECTRIC AND STEAM COSTS** | **NEW ANNUAL ELECTRIC COSTS** | **ANNUAL ENERGY SAVINGS** | **ESTIMATED PROJECT COST** |
| Compressor System Operations | $2,748,695 | $358,424 | $2,390,271 | $1,358,400 |
| Ancillary Air Equipment (dryers, etc.) | $404,327 | $0 | $404,327 | $423,400 |
| **Total Compressed Air System** | **$3,153,022** | **$358,424** | **$2,794,598** | **$1,781,800** |

It is directed into the regenerating tower, where the heat-of-compression removes the moisture from the desiccant. The air then flows back into the third stage of the compressor and then to the after-cooler, into the coalescing-type moisture separator, and into the drying tower where the air is dried to its final low dew point.

The towers switch every half hour. With a dew point demand system, the cycle is extended until the drying tower reaches saturation. At tower shift, a small temperature and dew point bump occurs, as with most other heat-reactivated dryers. The small amount of high dew point air blends in with the previously dried air to maintain a lower overall dew point.

The dew point demand system turns off the timer and switches the towers only when the dew point at the outlet of the dryer rises to a preset level indicating the desiccant in the dryer tower is saturated. Switching towers on demand uses the full capacity of the desiccant, reduces the number of tower shifts, reduced blower run and compressed air flow. The dew point demand system allows the dryer to be operated at 0 to 100% capacity.

## Conclusion

The savings potential of the over-all project totaled $2.8 million per year. The primary project was to eliminate the use of steam in both the air compressors and the air dryers. The plant is now set up to run much more efficiently and will see other benefits, such as reduced maintenance costs, derived from operating two rather than three air compressors. The project cost was $1.8 million resulting in a simple ROI of 8 months. BP

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