INDUSTRIAL COMPRESSED AIR SUPPLY SYSTEM EFFICIENCY

CONSULTANT REPORT

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COMPRESSED AIR SUPPLY EFFICIENCY

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COMPRESSED AIR SUPPLY EFFICENCY

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ABSTRACT

This project, under contract from California Energy Commission, developed the CASE (Compressed Air Supply Efficiency) Index as a stand-alone value for compressor central plant efficiency. This Index captures the overall efficiency of a compressed air system's supply side under typical plant operating conditions. Essentially, the index is a ratio of Standard Cubic Feet (SCF) of compressed air supplied by the central plant to the total number of kWh supplied over a given cycle period. The index can therefore be considered as a true output over input metric that measures the general performance of the supply side of a compressed air system in a similar way that the Miles Per Gallon (MPG) figure measures a vehicle's efficiency.

CASE Index has the units of Standard Cubic Feet (SCF) per kWh. It has a potential range of 0 to 325. Higher indices represent better efficiencies.

Five on-site tests were conducted on compressed air systems in various manufacturing plants. The sites varied in size from 75 horsepower to 650 horsepower. CASE Indices at these sites varied from 128 to 245.

BACKGROUND

Industry sources estimate the total connected load for compressed air in the US is over 17 million horsepower. For most industrial facilities, compressed air is a necessary part of the manufacturing operation. Generating compressed air is an energy intensive process, and for majority of industrial operations, the energy cost fraction of compressed air is significant in comparison to their overall energy costs. Yet there is a vacuum of reliable information on the energy efficiency of a typical compressed air system.

In industrial sites air compressors with auxiliary equipments like dryers, filters, etc., are usually located in a central place, and this area is called the compressed air central plant. The overall energy efficiency of the compressed air system is greatly affected by the full load and part load compressor efficiencies, the control system that operates and sequences the compressors, and various other equipments in the central plant. The full load efficiencies of compressors are well quantified and understood by the operators. But the other factors that significantly affect the overall efficiency are not quantified and are vaguely understood by the operators. As result of all these, the true efficiency of the total system is often very low. To make things even worse, there is no metric available at this time to benchmark the system performance and to track future improvements.

This project aimed at developing an acceptable form of metric with procedure to address this issue.

BENEFITS OF CASE INDEX

Developing an acceptable procedure to determine the system efficiency will have several benefits to the customer and the industry as a whole.

- Compressed air system operators will have an accepted procedure to assess their system performance and compare it against others.
- System operators will have a tool for monitoring the system performance on a real time basis, and set trigger points for intervention. It will prevent drastic losses of efficiency due to control failures and other reasons. Such failures are commonplace for compressor systems.
- The CASE Index will provide a way to quantify energy savings from system improvements, and thus facilitate system improvement projects. It will lead to energy savings.
- This will provide an acceptable metric for energy efficiency program development and administration of rebate programs.
- System efficiencies will be quantified and benchmarked on many systems. It will lead to statistical graphs with mean, median, and such statistics, on compressed air central plants. This will facilitate monitoring of efficiencies for regulatory and governmental agencies at local, state, and federal levels.

These benefits were well understood by the compressed air industry experts in Southern California from the outset. Their enthusiastic support to Southern California Edison Company by way of lending equipment, site selection, and technical advice, made this project a success.

PROJECT STEPS

Determination of CASE Index involves metering energy (kWh) flowing into and the compressed air (SCFM) flowing out of the central plant. Metering kWh is routine, and does not involve complications. But metering compressed air flow is a different case. Reliability of flow data was recognized to be a major problem from the beginning. So the project was essentially divided into two parts:

- Evaluation and assessment of accuracy of various compressed air flow measurement devices.
- On site testing of selected metering systems and developing the CASE Index. Five test sites were completed so far.

Evaluation and Assessment of Flow Metering

Following is a brief summary of available flow meters and their reliability issues:

- **Inferential Mass Flow Meters**

    1. Orifice plate
        - Turn down ratio: 10 : 1
        - Piping Modifications
        - System Shut down
        - **Flow obstruction**
        - **Permanent Pressure Loss**
        - **Crud build-up**

    2. Venturi tube
        - Same as above

    3. Pitot tube
        - Hot tap possible
        - Strict range limitations, Reynolds Number 200+
        - **Interference of particles, water droplets, etc.**
        - **Frequent cleaning and calibration**

    4. Magnetic Flow Meters
        - EMF proportional to fluid flow
        - Does not work for Compressed air due to **Conductivity of air**

    5. Positive Displacement Flow Meters
        - Impeller, rotating discs, sliding vanes, turbine, etc.
        - Turn down ratio: 10:1 or may be 20:1
        - **Sensitive to contamination of bearings**

- **Direct Mass Flow Meters**

    1. Constant Temp. TMF
        - Eldridge Products, Inc.
        - 2 Platinum RTDs
        - Turn Down Ratio: 1000:1
        - Fast Response
        - **Sensitive to Water droplets**

    2. Constant Power TMF
        - Turn down ratio: 100:1
        - Three RTDs
        - **Slow Response**

An advisory panel consisting of industry experts recommended insertion type direct mass flow meters only for evaluation. Other types of flow meters were ruled out due to the issues presented above.

Even among the Mass Flow meters, accuracy and reliability were of concern. So test facility was set up in the SCE laboratory to evaluate flow meters selected by the advisory panel. The test set up is shown below:

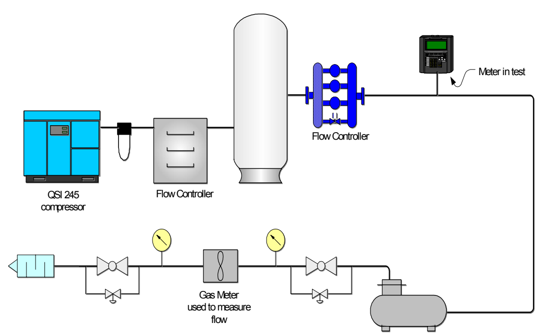


Figure 1. Test Bench

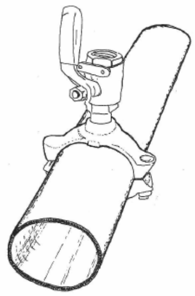
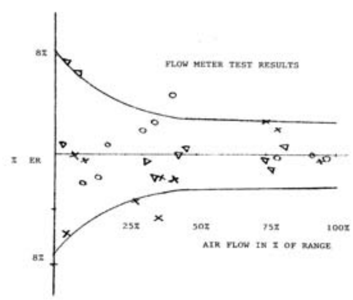


Figure 2. Hot Tap for Flow Meter

Flow meters from Eldridge, Fluid Components International, Sierra Instruments, and Trak Air, were evaluated in the SCE Laboratory against a positive displacement control flow meter, Aerzna DN 65.

Results from these tests are summarized and presented in the graph below:



X Axis - % Full Scale	1. Eldridge 8240MPNH
Y – Axis - % Error	2. FCI ST 98
	3. Sierra 640S-M8
	4. Trak Air

Figure 3. Flow Meter Test Results

Initial compressed air flow metering efforts resulted in about 65% failure rate, in spite of strict adherence of calibrations and procedures recommended by the flow meter manufacturers. Human errors at the testing and calibration laboratories were the reasons for the failures in all but one case. The graph presented above, represents the data after the corrections were made. Subsequent efforts to avoid the human errors have yielded an almost 100% success rate to date.

<u>On Site Testing</u>

The second step in this project was to test the procedure on working compressor systems. Five systems, varying in size from 75 to 650 horsepower, were studied in an effort to fine tune the procedure and to work out any problems related to installations and metering, and to develop overall familiarity with the metering equipment and mounting. A schematic of the equipment and metering devices is presented below for one of the five systems that was studied.

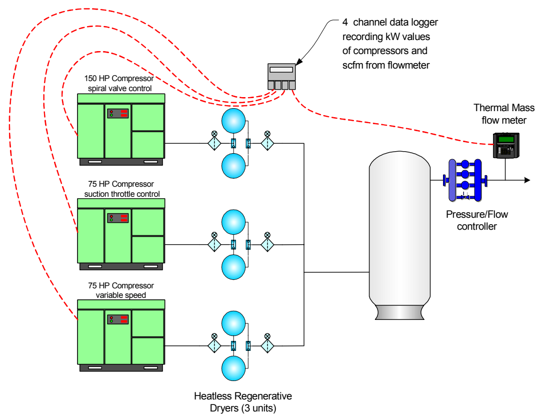


Figure 4. Compressor System for Site # 3

In the procedure developed, compressed air flow rate is sampled four times per minute (once every 15 seconds) and the average of the four samples is recorded on a data logger every minute for an entire week. Energy supplied to compressors and other auxiliary equipments are also metered and recorded on the same time interval. All metering points are time synchronized to aid in the analysis and diagnosis of problems. The program calculates the index minute by minute, and prints it along with the SCFM, and the total and individual kWh consumed. The CASE Index will vary between 0 and about 325. Higher numbers indicate better efficiencies. The average CASE Index for the entire week is calculated, and that becomes the efficiency statistic for the system.

In the case presented above the compressors were 16 and 20 Series Sullair compressors (75H and 150H). The two 75 HP compressors supported the plant, and the 150 HP was a stand-by for service. The maximum CASE Index potential for this system is around 293 (SCF/kWh). The actual performance turned out to be 193. Considering the system set up with VSD compressor for trimming, the actual performance (CASE Index of 193), was way below that was expected. The results immediately indicated a need for a better sequencing control. In this case, the engineers in this plant set up a new controller with a PLC that operated based on the data coming from the flow meter.

RESULTS

Results from the five on site tests are summarized below.

	HP	CASE Index	CASE Ind (max)	Remarks
Site 1	75 30+30+15	**128**	300	Many improvement opportunities. Financially not justifiable due to small system size
Site 2	300 150+75+75	**193**	293	New controller for sequencing. **122,500 kWh annually**
Ste 3	650 4x125+150	**215**	300	Suspected solenoid malfunction. Being traced. Energy impact unknown.
Site 4	600 4x150	**243**	312	Replace QSI490 with 150 HP VSD compressor**. 617,000 kWh annually.**
Site 5	130 2x40+2x25	**241**	286	Replace all four with 100 HP VSD unit. **88,000 kWh annually**

Table 1. Summary of On Site Test Results

Typical Report

The study issues a final report on the system performance with a Summary Section and the Data File. The Data File contains about 12,000 individual lines of data. The Summary Section and a brief portion of the Data File for one of the sites are below.

COMPRESSED AIR SYSTEM EFFICIENCY

CASE INDEX - XXX Irvine

SUMMARY OF RESULTS

- **Average CASE Index was 193**
- **CASE Index ranges was from 58 to 286**
- **This was the result of a one week study – 2/12/03 to 2/19/03**
- **CASE Index measures the overall efficiency of the compressed air system. Higher number indicates higher efficiency. Improvement of 10 units in CASE Index is equal to saving 35,000 KWH a year for this installation.**

Two strategies to improve the Index without much capital investment:

1. Shut down the Base Compressor from 1.15AM to 4.45 AM
   Estimated new CASE Index: 210
   17 Index points improvement – 59,500 KWH/Year savings
2. Use the flow meter to shut down Base Compressor at 220 SCFM and restart at 280 SCFM.

   Estimated new CASE Index: 228
   35 Index points improvement – 122,500 KWH/Year savings

XXX Irvine could install a 100 HP compressor with VSD. This would be sufficient to supply the plant 24 hours a day, and will improve the CASE Index even higher.

Figure 5. Summary of Report

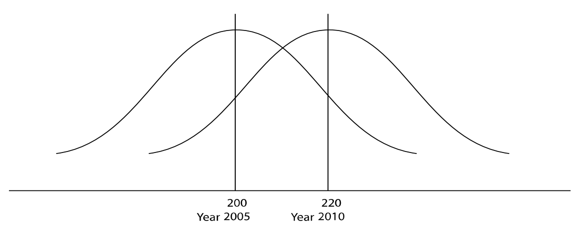
Date/Time	North QSI 490 kW	North QSI 500 kW	North flow SCFM	South QSI 500 kW	South QSI 500 kW	South flow SCFM	Total Flow SCFM	Total KW	CASE Index
9/11/03 12:00 PM	90.82	91.66	613.4	73.62	77.88	676.9	1290.4	333.98	**231.82**
9/11/03 12:01 PM	90.97	91.89	624.8	75.98	76.97	661.1	1285.9	335.81	**229.76**
9/11/03 12:02 PM	90.75	91.89	637.6	77.80	77.04	657.0	1294.6	337.48	**230.16**
9/11/03 12:03 PM	90.67	91.89	622.6	76.21	76.74	647.6	1270.2	335.50	**227.16**
9/11/03 12:04 PM	90.29	91.89	631.8	74.53	76.21	628.7	1260.5	332.91	**227.18**
9/11/03 12:05 PM	89.91	91.66	622.3	74.61	76.05	627.6	1249.9	332.23	**225.74**
9/11/03 12:06 PM	89.68	91.20	613.4	74.68	76.51	632.5	1245.9	332.08	**225.12**
9/11/03 12:07 PM	89.91	91.36	616.8	74.91	76.66	631.0	1247.8	332.84	**224.94**
9/11/03 12:08 PM	89.83	91.13	629.0	74.53	76.66	641.9	1271.0	332.15	**229.59**
9/11/03 12:09 PM	90.52	91.43	644.0	74.99	77.12	659.6	1303.7	334.06	**234.15**
9/11/03 12:10 PM	90.75	91.81	641.0	76.74	77.12	664.5	1305.5	336.42	**232.84**
9/18/03 11:59 AM	0.00	90.59	413.8	89.07	87.70	888.2	1302.0	267.37	**292.19**
9/18/03 12:00 PM	0.00	90.44	415.0	88.77	87.09	892.0	1307.0	266.30	**294.48**
Averages			**640.0**				**1391.4**	**344.25**	**243.11**

Table 2. Data File

FUTURE STUDIES

This is a very useful tool for benchmarking compressor system efficiencies. Many companies have multiple plants, and would want to have a benchmarking tool to document, compare, and track system efficiencies for various plants within the corporation. In the studies presented above, site #2 and #5 belong to the same corporation. After the first study, engineers for this corporation recognized this as a benchmarking tool, and are now involved in studying the compressor systems in several plants.

Utilities and regulatory agencies could quantify system efficiencies and develop statistical histograms for a geographical area and track progress of energy efficiency efforts. If the histogram in 2005 yields an



average CASE Index of 200, and a similar curve yields 220 in year 2010, the progress in the five year period can be claimed to be 20 CASE Index points or 10% for the area.

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