the new Paradigm for Air Power in Refrigeration

INTRODUCTION

This white paper provides a proof of concept for AeraDIGM Convergent Refrigeration (CR). Both the background and the analytical support herein demonstrate the viability of well-known commercial pumps in delivering needed efficiencies for low pressure air flows. Indeed, this analysis shows that the air flows themselves can be supported with the energy budget of the fans they replace. Because the target application, CR, makes use of the adiabatic heating normally charged as waste when measuring these pumps as pumps alone, the adjusted allocation of the desired heating can be subtracted directly from the total cost of operation, exposing the net cost of moving air on its own.

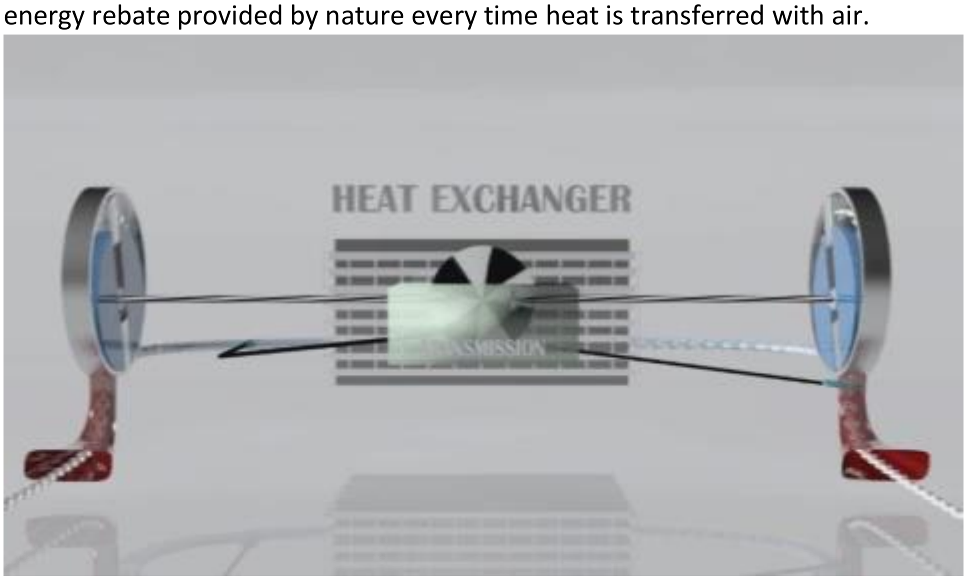
What is the least costly way to change the temperature of the air in the room?

- It has always been known and always understood that, whether heating or cooling, we pass the needed mass of air over the heat exchanger. Air has the needed heat capacity.
- It has long been known and often understood that heat transfers into the air faster when the approaching air temperature is farther away from the temperature of the heat exchanger.
- It has recently been known and rarely understood that 40% of the heat is lost in “free expansion” when potential work of expanding and contracting gasses is never captured.
- It has not been known and never understood that the cost of changing the air temperature before it hits the heat exchanger can be much less than the cost of changing the heat exchanger temperature by the same amount.

AeraDIGM provides a new technique for refrigerating by combining the power of all four of these principles in a single breakthrough for heating and cooling efficiency.

The Better Way: Fan Replacement and Refrigerated Air Flows

1. AeraDIGM places the heat exchanger between two pumps. It is possible to capture the 40% energy rebate provided by nature every time heat is transferred with air.



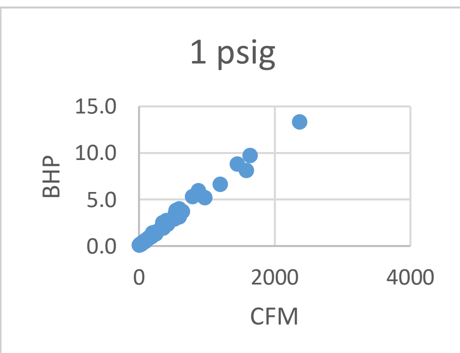
2. AeraDIGM delivers the fastest efficient means of changing the temperature of a mass of air (by changing its pressure).
3. AeraDIGM secures the most favorable temperature gradient between air and any convective heat source or sink. It costs less to change the temperature of the air than it costs to change the temperature of the source or of the sink.

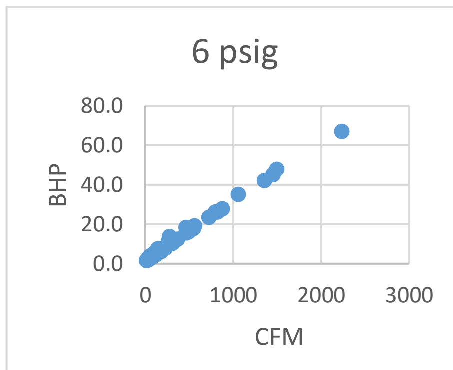
Proof: The 150 year Roots Blower certifies AeraDIGM viability

The following analysis identifies the cost of simply moving air separately from the cost of changing its pressure. The work related energy costs attributable to compression and expansion will be identified, while separately identifying the work related energy cost of moving air through the pump itself. It will be shown that once the compression energy (offset by expansion and work capture during heat transfer) is subtracted from total work input, the cost of moving air through the dual pump system is on a par with the cost of just moving the same mass flow of air with fans and blowers.

Standard commercial performance is specified for the whole family of Dresser URAI blowers in **Table 1**. Mass flows are comparable to air flows in refrigeration systems, normally driven by fans. The desired changes in pressure (temperature) changes are delivered within the same mass flow.

It can be seen in the following scatter plots at 1 psig and 6 psig that the energy cost to both move and compress a cubic foot of air increases roughly linearly across the range of flows and pressures, regardless of the device actually chosen.





These plots normalize the assortment of devices and mass flows stated in the tables. Because the proposed Refrigerated Air Flow (RAF) systems will operate primarily near atmospheric pressure ±10%, rarely exceeding 20% differences, only the 1 psi column contains data governing the relevant conclusions. Others provide confirming data beyond this range.

Rather than simply moving the air with a fan, the objective of a RAF system is to change the temperature of the same air before it comes in contact with a heat exchanger. Increasing this approach air temperature differential will increase the rate and amount of heat transferred by the same mass air flow. In conventional systems the ambient (target environmental) mass flow is passively fed across a heat exchanger whose temperature is separately engineered to provide the desired rate and direction of heat flow. Contrast this to RAF systems where the ambient mass flow becomes the refrigerant. The temperature of the RAF mass flow can then be engineered to provide the desired rate and direction of heat flow most often at a cost much lower than changing the temperature of the heat exchanger itself.

To make a valid comparison of the cost of moving air with a fan to the cost of moving air with a pair of compressors, it is only necessary to isolate the cost of adiabatic compression and subtract it from the total operating cost of the compressor. AeraDIGM will directly recover the compression cost with offsetting expansion work in the second pump, so the following three scenarios account for all three cases of heat in, heat out, and no heat transfer.

NO HEAT TRANSFER

For the case where no heat is transferred following compression, a follow-on expansion process might recover the entire energy cost of compression directly by complimentary mechanical means. The Roots Blower offers such a mechanism. Notably this energy recovery mode during expansion is different from both the compression operation and the vacuum pump for which data is available. But a free-wheeling exit pump would not sustain the plenum pressure as needed for heat transfer under constant pressure. An electrical load would be provided to the motor/generator governing the speed of the exit pump, making it act in a manner effectively identical to the entry pump. So the cost of compression would be exactly offset by expansion, accepting of course that there are losses to be recognized on both sides.

HEAT ACQUIRED

For the case where heat is acquired within the plenum, the resulting increase in volume will directly increase the energy recovered at exit, indeed this becomes a "heat engine". The introduction of heat between the two pumps is analogous to a jet aircraft engine, producing a direct energy yield due to the introduction of heat. Indeed, as defined by the coefficient of heat under constant pressure, nature provides an energy bonus equal to 40% of the heat acquired, a volume increase which can produce electricity to offset the power used by the pumps.

HEAT REJECTED

For the case where heat is rejected within the plenum, the resulting decrease in volume will directly decrease the energy recovered at exit. In this case the departure of heat from the mass within the plenum reduces the volume (not mass) within the plenum. Strikingly, this reduction of volume affects the system and its net energy in a manner analogous to the "heat engine" behavior described above. Because the plenum pressure must be reduced by the exit pump, this energy expenditure is offset by the energy recovered at the entry, work equal to 40% of the heat transferred, as above, even though the volume between the two pumps is reduced.

When all is said and done, the transfer of heat makes a 40% energy contribution to offset the losses related to compressing and expanding air. This net contribution may substantially offset pumping losses depending on the capability of the pumps as well as on the compression ratios and the heat finally transferred. Because this exercise is limited to a pressure of 1 psig, a pressure ratio of 1.068, it can be confidently assumed that compression costs will be offset by expansion gains and vice-versa. Looking at the operating energy requirements reported by Dresser, the full value of compression energy may be subtracted from the operating energy cost, leaving all losses chargeable to air movement alone.

The compression efficiencies for each entry in the Dresser table have been identified and sorted in the order of increasing compression efficiency. This is shown in the right hand column. Any pump actually designed and developed for these low pressure ratios will easily meet or exceed the best performance of this 150-year-old design. Because the Roots Blower was intended for much higher pressure ratios, it is appropriate to benchmark compression performance at 90%, knowing that the entire cost of compression and expansion will be directly offset, i.e. zeroed out. Dresser Frame #718 delivers 1590/0.81 CFM/BHP total or 2628 CFM/Kw for air movement alone, after the cost of compression has been removed.

Compared to residential HVAC air flows (2,000 CFM/Kw inside and 4,000 CFM/Kw outside), any such 2628 CFM/Kw unit will deliver heating and cooling comfortably within the energy budget of present fan systems alone.

Frame Size	Speed RPM	1 PSI						
		CFM	BHP	ft*lbf/min	ft*lbf (ΔT)	Air Movement cost=E-F	Air Movement cost/Total	Efficiency=T/total
22	1160	10	0.1	3300	1510	1790	54.25%	45.75%
24	1160	24	0.2	6600	3624	2976	45.09%	54.91%
53	2850	355	2.5	82500	53601	28899	35.03%	64.97%
65	2350	546	3.8	125400	82441	42959	34.26%	65.74%
42	3600	204	1.4	46200	30802	15398	33.33%	66.67%
76	2050	790	5.3	174900	119282	55618	31.80%	68.20%
59	2850	881	5.9	194700	133022	61678	31.68%	68.32%
56	2850	598	4.0	132000	90292	41708	31.60%	68.40%
45	3600	410	2.7	89100	61906	27194	30.52%	69.48%
22	5275	76	0.5	16500	11475	5025	30.45%	69.55%
47	3600	542	3.5	115500	81837	33663	29.15%	70.85%
68	2350	876	5.6	184800	132267	52533	28.43%	71.57%
45	860	79	0.5	16500	11928	4572	27.71%	72.29%
22	3600	49	0.3	9900	7399	2501	25.27%	74.73%
36	3600	344	2.1	69300	51941	17359	25.05%	74.95%
711	2050	1450	8.8	290400	218936	71465	24.61%	75.39%
32	3600	149	0.9	29700	22498	7202	24.25%	75.75%
65	1760	400	2.4	79200	60396	18804	23.74%	76.26%
615	2350	1641	9.7	320100	247775	72325	22.59%	77.41%
24	3600	102	0.6	19800	15401	4399	22.22%	77.78%
33	3600	205	1.2	39600	30953	8647	21.84%	78.16%
24	5275	156	0.9	29700	23554	6146	20.69%	79.31%
33	2800	156	0.9	29700	23554	6146	20.69%	79.31%
68	1760	643	3.7	122100	97087	25013	20.49%	79.51%
76	575	192	1.1	36300	28990	7310	20.14%	79.86%
36	2800	262	1.5	49500	39559	9941	20.08%	79.92%
47	860	105	0.6	19800	15854	3946	19.93%	80.07%
65	700	140	0.8	26400	21139	5261	19.93%	80.07%
76	1400	527	3.0	99000	79572	19428	19.62%	80.38%
56	700	123	0.7	23100	18572	4528	19.60%	80.40%
53	1760	211	1.2	39600	31859	7741	19.55%	80.45%
718	2050	2370	13.3	438900	357846	81054	18.47%	81.53%
56	1760	358	2.0	66000	54054	11946	18.10%	81.90%
53	700	72	0.4	13200	10871	2329	17.64%	82.36%
59	1760	529	2.9	95700	79874	15826	16.54%	83.46%
615	1760	1205	6.6	217800	181943	35857	16.46%	83.54%
615	700	420	2.3	75900	63416	12484	16.45%	83.55%
33	1160	55	0.3	9900	8304	1596	16.12%	83.88%
42	1760	92	0.5	16500	13891	2609	15.81%	84.19%
711	1400	970	5.2	171600	146460	25140	14.65%	85.35%
68	700	224	1.2	39600	33822	5778	14.59%	85.41%
59	700	187	1.0	33000	28235	4765	14.44%	85.56%
45	1760	188	1.0	33000	28386	4614	13.98%	86.02%
32	2800	113	0.6	19800	17062	2738	13.83%	86.17%
36	1160	95	0.5	16500	14344	2156	13.07%	86.93%
42	860	38	0.2	6600	5738	862	13.07%	86.93%
711	575	362	1.9	62700	54658	8042	12.83%	87.17%
47	1760	249	1.3	42900	37597	5303	12.36%	87.64%
718	575	600	3.1	102300	90594	11706	11.44%	88.56%
718	1400	1590	8.1	267300	240074	27226	10.19%	89.81%
32	1160	40	0.2	6600	6040	560	8.49%	91.51%

Developmental opportunities beyond Roots Blowers for advancing AeraDIGM Fan Replacement and Convergent Refrigeration

The common Roots Blower was initially developed 150 years ago for high compression applications. It is machined from cast metals. Even when adapted for supercharging high performance automotive vehicles, the lighter weight versions of the Roots Blower still rely on machined castings. In US 7,621,167: Method of Forming a Rotary Device, the inventor teaches methods for replacing such castings with light weight roll formed products that inexpensively deliver as much as three orders of magnitude better surface finish than the best attainable machined casting. The results displayed above can be mass produced without further innovation. Much more importantly, the combination of inexpensive mass production with the disruptive market opportunity presented by Convergent Refrigeration invites innovation first of all with newer AeraDIGM pump designs and form factors specifically engineered to low pressures with high mass flow, overcoming the inherent limitations of the high compression products they replace. Their success will invite the investigation of similar rolled steel product innovations for a considerable range of pumps and pump-like products now made with cast metal.

Conclusion

The analysis has identified several factors which control the energy needed to change the pressure of a mass flow of air between two pumps, delivering AeraDIGM's air power in refrigeration.

- Whether the temperature between the pumps is changed or not, and whether heat is transferred or not, the complimentary compression/expansion energy can be definitively identified.
- Subtracting this fully recovered compression/expansion energy component from the total pumping energy reveals the cost of moving air through the system, nominally through the connected system where the follow-on pressure is measured only in inches of water.
- The cost of moving air through the AeraDIGM dual pump system may be well below the cost of moving the same mass flow of air with fans in most circumstances.

Table 1 – Dresser Roots UARI Spec. 22-718

Frame Size	Speed RPM	1 PSI		6 PSI		Max. Vacuum		
		CFM	BHP	CFM	BHP	"HGV	CFM	BHP
	1160	10	0.1			46		0.2
22	3600	49	0.3	38	1.6	14	28	1.8
	5275	76	0.5	64	2.4	15	53	2.8
	1160	24	0.2			6	12	0.5
24	3600	102	0.6	83	3.1	14	69	3.5
	5275	156	0.9	137	4.6	15	119	5.5
	1160	40	0.2	21	1.4	10	18	1.1
32	2800	113	0.6	95	3.4	15	78	4.1
	3600	149	0.9	131	4.4	16	110	5.3
	1160	55	0.3	31	1.9	10	27	1.5
33	2800	156	0.9	132	4.6	14	113	5.2
	3600	205	1.2	181	6.1	15	159	7.3
	1160	95	0.5	61	3.1	10	55	2.5
36	2800	262	1.5	229	7.7	12	213	7.5
	3600	344	2.1	310	10.1	15	278	12.1
	860	38	0.2	18	1.4	8	19	0.9
42	1760	92	0.5	72	2.8	14	56	3.2
	3600	204	1.4	183	6.1	16	160	7.7
	860	79	0.5	42	2.7	8	46	1.8
45	1760	188	1.0	151	5.7	12	134	5.5
	3600	410	2.7	374	12.2	16	332	15.4
	860	105	0.6	59	3.6	8	63	2.4
47	1760	249	1.3	203	7.5	12	181	7.3
	3600	542	3.5	496	16.1	15	452	19.1
	700	72	0.4	42	2.4	10	36	2.0
53	1760	211	1.2	181	6.3	14	158	7.1
	2850	355	2.5	325	10.7	16	291	13.4
	700	123	0.7	78	4.1	10	70	3.3
56	1760	358	2.0	312	10.5	14	276	11.8
	2850	598	4.0	553	17.7	16	501	22.4
	700	187	1.0	130	5.9	8	135	3.9
59	1760	529	2.9	472	15.3	12	445	14.9
	2850	881	5.9	824	26.0	15	770	30.8
	700	140	0.8	93	4.5	12	71	4.4
65	1760	400	2.4	353	11.9	16	300	15.2
	2350	546	3.8	499	16.4	16	445	25.6
	700	224	1.2	149	7.3	10	135	5.9
68	1760	643	3.7	567	18.9	15	495	22.7
	2350	876	5.6	801	25.9	16	715	32.8
	700	420	2.3	279	13.6	8	292	8.9
615	1760	1205	6.6	1063	34.9	12	997	33.9
	2350	1641	9.7	1500	47.6	14	1389	53.4
	575	192	1.1	134	6.1	12	117	6.0
76	1400	527	3.0	468	15.4	16	413	19.7
	2050	790	5.3	731	23.4	16	674	29.5
	575	362	1.9	271	11.1	12	228	10.9
711	1400	970	5.2	880	27.7	15	793	33.5
	2050	1450	8.8	1359	41.8	16	1256	53.1
	575	600	3.1	470	18.1	10	446	14.8
718	1400	1590	8.1	1460	44.8	12	1398	43.6
	2050	2370	13.3	2240	66.9	12	2178	64.7