

Cost Saving, Energy-Efficient DEEP Coil Technology

High Impact, Low Cost Solution

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To be cost-effective and energy efficient, a forced-air fin-tube heat exchanger should ideally transfer all of available heat (absorb or reject) with minimal amount of resistance to air movement over the tubes, as well as fluid movement within the tubes. The lower the air side resistance, lesser will be the fan motor power consumption. Similarly, lesser the fluid resistance inside the tubes, lesser will be fluid pump/compressor power consumption.

The DEEP coil achieves these goals by reducing fin density, increasing tube spacing, and increasing the tube rows. The combined result of reduced fin density and the increased fin spacing provides for reduced air side resistance, allowing for much smaller fan power. Increasing the tube rows increases the real-time contact between the two heat exchanging media, namely fluid inside the tubes and air flowing through the heat exchanger.

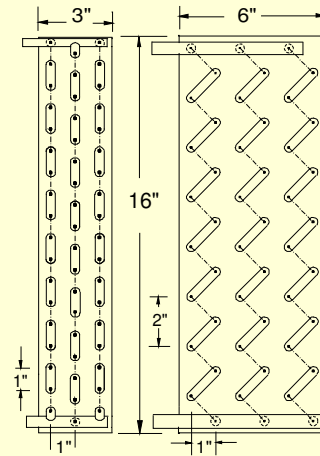
Based on the above principle, true production-quality prototype samples were made from custom-designed tooling, particularly the fin dies. Four samples, each 16" x 36" (4 sq.ft.) face dimension, but with some variations in fin density or number rows, were made. These samples were tested at Intertek Testing Services (I.T.S./ETL) laboratories, Cortland, NY. In the following table these coils are designated as D1, D2, D3 and D4. Their equivalent current-design coils are designated T1, T2, T3 and T4. The equivalent current-design The Thin coil has exactly same total length of copper tubing and fin square footage. Both coils use 0.016" 3/8" copper tubes and 0.008" thick aluminum fins.

ACFM/FPM	DEEP Coil Sample					Equivalent Thin Coil Sample					BHP/10k Ratio
	No.	BTUH	Sp	Fan BHP	BHP/10K	No.	BTUH	Sp	Fan BHP	BHP/10k	
800/200	D1	23,688	0.027	0.0043	0.00180	T1	24,868	0.1	0.0158	0.0064	0.28
1200/300	D1	28,700	0.052	0.0123	0.00430	T1	32,079	0.2	0.0475	0.0148	0.29
1600/400	D1	31894	0.084	0.0266	0.00833	T1	37,444	0.32	0.1013	0.0270	0.31
2000/500	D1	35,414	0.125	0.0494	0.01396	T1	41,551	0.47	0.1859	0.0447	0.31
800/200	D2	20,837	0.01	0.0016	0.00076	T2	23,881	0.07	0.0111	0.0046	0.16
1200/300	D2	25,972	0.03	0.0071	0.00274	T2	30,784	0.14	0.0332	0.0108	0.25
1600/400	D2	30,259	0.06	0.0190	0.00628	T2	35,868	0.25	0.0728	0.0203	0.31
2000/500	D2	34,186	0.09	0.0356	0.01041	T2	39,728	0.34	0.1345	0.0339	0.31
800/200	D3	20,709	0.017	0.0027	0.00130	T3	23,541	0.08	0.0127	0.0054	0.24
1200/300	D3	25,884	0.035	0.0083	0.00321	T3	30,163	0.15	0.0356	0.0118	0.27
1600/400	D3	29,819	0.06	0.0190	0.00637	T3	34,770	0.24	0.0760	0.0218	0.29
2000/500	D3	33,243	0.087	0.0344	0.01035	T3	38657	0.35	0.1385	0.0358	0.29
800/200	D4	18,621	0.01	0.0016	0.00085	T4	22,264	0.05	0.0079	0.0036	0.24
1200/300	D4	23,241	0.024	0.0057	0.00245	T4	28,326	0.11	0.0261	0.0092	0.27
1600/400	D4	27,105	0.043	0.0136	0.00502	T4	32,808	0.18	0.0570	0.0174	0.29
2000/500	D4	29,999	0.067	0.0265	0.00883	T4	36,242	0.26	0.1028	0.0284	0.31

Tests were conducted at 135°F inlet water, 3 gpm, 95°F inlet air. Following table compares actual data recorded on DEEP coils with the equivalent thin coil data obtained from coil selection software.

Coil Spec.s

Coil	Tubing, Ft	FPI	Fin Area Sq. ft.	Rows
D1/T1	192/192	8/16	256/256	8/4
D2/T2	192/192	6/12	192/192	8/4
D3/T3	144/144	8/16	192/192	6/3
D4/T4	144/144	6/12	144/144	6/3



Conversion of 1 x 1" to 2 x 1" DEEP coil

Fan BHP - calculated as per:
$$FanBHP = \frac{(scfm \times sp \times sp.gr.)}{(6356 \times fan \cdot eff.)}$$

where specific gravity =1, Assumed fan eff. = 0.7 and SCFM = approx.0.88 x ACFM

Sp - static pressure in "of water column, BHP/10k BTU – Fan BHP per 10,000 BTU heat

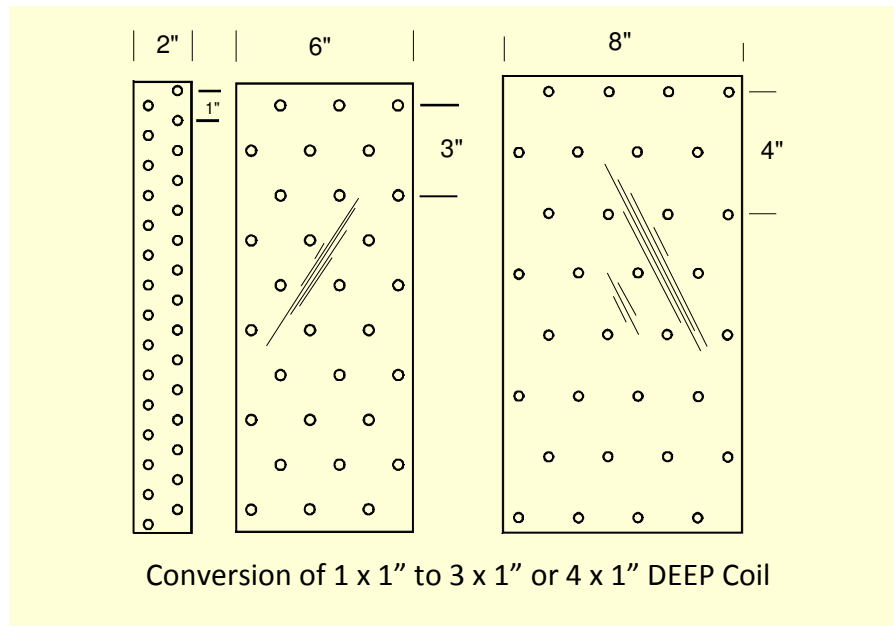
BHP/10k Ratio – (BHP/10k for DEEP coil) / (BHP/10k for Thin Coil); Example: D4 Coil:
0.00883/0.0259 = 0.34

Coil T1- 4 Row, 16 fpi, 2 feeds; Coil T2- 4 Row, 12 fpi, 2 feeds; Coil T3 – 3 Row, 16 fpi, 3 feeds; Coil T4-3 Row, 12 fpi, 3 feeds; all 1x 1" tube spacing

Coil D1 – 8 Row, 8 fpi, 2 feeds; Coil D2 – 8 Row, 6 fpi, 2 feeds; Coil D3 – 6 Row, 8 fpi, 3 feeds; Coil D4 – 6 Row, 6 fpi, 3 feeds; all 2 x 1" tube spacing

The deficient heat transfer capacity in DEEP coils (D1, D2..) relative to equivalent thin coils (T1, T2..) is due to lack of any fin formation such as corrugations, louvers or sine wave in DEEP coils. These fin formations will bring up the BTU capacity as well as increase the air resistance. However, given the low fin density of DEEP coil, the BTU heat transfer increment will be higher than the air resistance gain, providing net gain. The ratio "BHP/10k" was derived to alleviate likely misinterpretation of the above data.

Due to lack of proper tooling, the return bends in the above samples were made by joining two 90 degree pieces instead of one smooth semicircular piece. Because of the tow sharp bends in each tube return and the additional brazing fluid pressure drop was excessive and non-representative.



Where in the world!!

The above is an example of conventional thin coil conversion to DEEP coil. In this case a 1" x 1" tube spacing, 2 row, 15 fpi thin coil is converted to 3" x 1", 6 row, 5 fpi DEEP coil. Both coils use same heat transfer material, quantity and type. Also, the material is just as uniformly and evenly distributed in the converted coil. The short air path (small dwell time) thin coil is converted to 3 times as long air path (3 times longer dwell time), low fin density, and high row DEEP coil. The combination of low fin density and high tube spacing provides reduction in fan power. The high tube spacing (3" turning diameter) provides 2/3rd fluid resistance reduction in return bends, which is compressor/fluid pump power reduction. And, the 6 rows provide for 3 times longer actual dwell time compared to the thin coil. The 2" coil has now become 6" deep. At the outset, it may appear that this would increase the cabinet size, length or height, by 4". But, the resulting smaller fan will require smaller upstream/downstream clear space needed for uniform and clean airflow, which will nullify the added depth to the coil. Also, since the face area is same, this will warrant minimal changes to the existing cabinet of the end product. Since, relative to micro channel coils as an example, this coil does not interfere with the existing refrigeration cycle, electrical controls, and overall configuration, it will require minimal re-evaluation from safety compliance agencies like UL or ETL. Major cost/time savings!

The above figure also shows conversion of the same coil to 4 x 1" pattern, 4 fpi, 8 row coil. This will reduce the fluid side resistance in return bends to 1/4th of the original, the air side resistance to a range of 15-20% of the original, and provide essentially same BTU heat transfer.

In the above data, the heat transfer capacities for DEEP coil are about 15% below equivalent thin coil. For example, Coil D4 has 29,999 BTUs as compared to 36,663 BTUs for Coil T4. This can be largely corrected by more pronounced fin formation such as corrugation or sine wave to the DEEP coil D4, which has flat fins. This will increase both the heat transfer and the air resistance, but will still provide substantial energy savings without adding more fins. In the above table, the fan BHP/10,000 BTU for DEEP coil is only about 30% of the equivalent thin coil, which is 70% reduction in fan power. This ratio will get considerably smaller for 3 x 1" and 4 x 1" patterns, meaning still larger power savings.

The fan power reduction of 20%+ comes from reduction in the air side resistance. The relevant mathematical formula is:

$$\text{BHP2} = \text{BHP1} \times (\text{sp2/sp1})^{1.5}$$

The fluid pump/compressor power reduction comes from reduction in the tube resistance. The DEEP coil has much larger tube spacing, for example 2" x 1" as compared to most common 1" x 0.866" for thin coils. Due to larger spacing, the return bends are, in this case, 2" diameter as compared to 1" diameter. The much softer return bends due to the large turning diameter allows for reduction in fluid resistance of 20%+. The resistance in return bends is mostly centrifugal force which is:

$$f = mv^2/r.$$

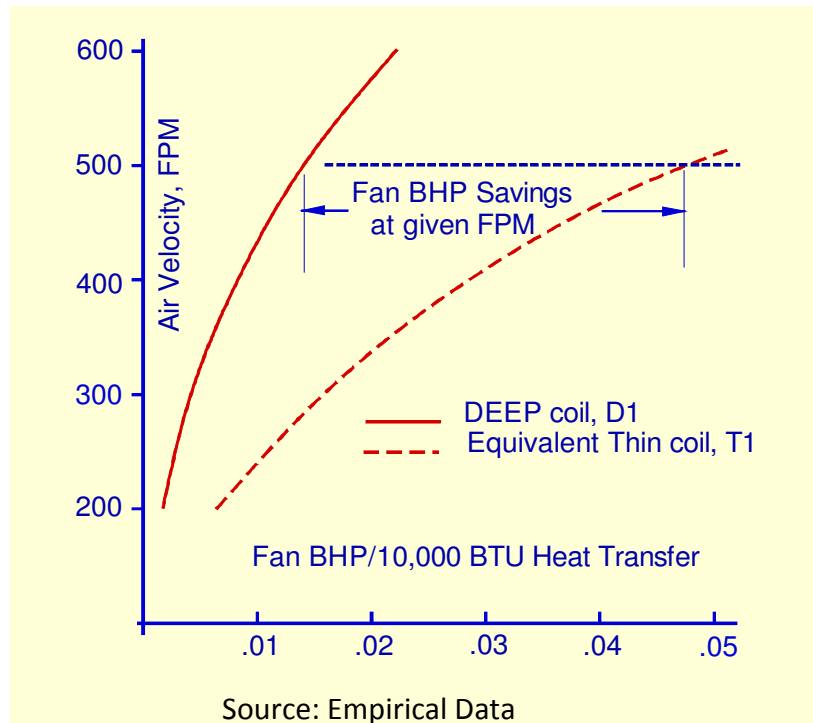
Accordingly, if the radius is doubled, the force is halved, which is fluid side resistance is halved.

The reduced fan power (which is reduced fan motor hp), and the reduced pump/compressor power (which is reduced pump/compressor motor hp) allows for lower OEM cost and, concurrently, allows for lower operating cost.

It is entirely realistic that for a current air conditioning or refrigeration machine, when implemented with 4 x 1" tube pattern coil, the compressor and fan motor size will reduce to half from the current levels.

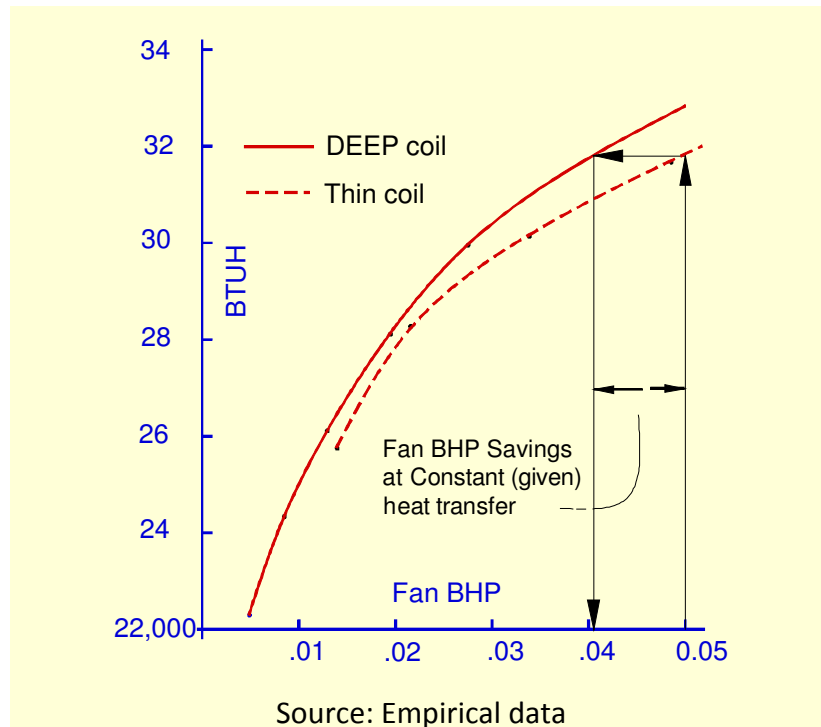
The following is a graphical representation of the above empirical test data for test samples D1 and T1. However the pattern repeats for all 4 coil samples.

It is entirely realistic that for a current air conditioning or refrigeration machine, when implemented with 4 x 1" tube pattern coil, the compressor and fan motor size will reduce substantially to levels not achieved today, while retaining the same heat transfer capacity.



From the above graph, unlike DEEP coil, the thin coil heat transfer seems to plateau beyond 500 fpm velocity. That is, any increase in velocity will cause disproportionate increase in the fan power. This means, with the DEEP coil, the threshold velocity can be increased beyond 500 fpm to perhaps up to 700 fpm. This is significant in that it will allow a design engineer to shrink the footprint of the end product.

The following is another graphical representation of comparison between DEEP coil and equivalent thin coil. In this case, test data on both coils is empirical. Both coils have the same tube and fin material, both type and quantity.



The DEEP coil is particularly effective in outdoor condensers which use propeller fans. The propeller fans are sensitive to static pressure. The DEEP coil reduces the air resistance (static pressure) significantly. The current 1 row, 24 fins per inch, U shaped coil can be converted to multiple row, low fin density, slab coil with low static pressure. A large 6 or 8 sq.ft, 1 row, 24 fins per inch coil can be converted to DEEP coil with face area in the neighborhood of 2 -3 sq.ft., and reduce the overall footprint of the unit.

Similarly, the conventional “slab” coil can be converted to DEEP coil configuration and achieve all the benefits. Please see the above example of 2 row coil conversion to 6 row coil.

Another Angle:

The basic formula for heat transfer to air is:

$$\text{BTU (sensible)} = \Delta t \times \text{CFM} \times 1.08$$

In a typical R-22 air conditioning condensing unit, the available temperature difference between the hot refrigerant and the air is equivalent to about 30°F. Complete heat transfer at minimum CFM will occur when the air temperature rise reaches 30°F. However, most of the current condenser units operate around 10+/- degree rise. That means, to allow complete heat exchange, you need to move about 3 times as much air. The DEEP coil, due to its unique ability to provide long dwell time, will allow the temperature rise to be close to 20°F. Compared to the thin coil, 20°F rise will result in half as much air movement. That is half as much fan power. Only DEEP coil would let this happen. It is antithetic to single row, high fin density, tight tube spacing, U shaped coil.

It may not be inappropriate, or out of order, to say that, at this stage, to pursue more research in high fin density, tight tube spacing, 1 or 2 row, U-shaped or slab coil may be getting close to 'churning water'. Whereas, DEEP coil is a child just born! There is plenty of room to grow and evolve! There are many variables, and lot of data to be collected and converted into coil-selection software. Global warming true or not, efficiency is efficiency, and efficiency is always better than inefficiency. Can't afford to ignore for any world class HVAC/R manufacturer!



Hemant D Kale, inventor of the DEEP coil, holds BSME from University of Bangalore, has completed course work for MSME degree (Illinois Institute of Technology), course work for MBA (Roosevelt University, Chicago, IL) and is a Registered Professional engineer in the State of Illinois. Mr. Kale has 35 years of experience in all facets of the HVAC/R industry and has worked for many world-leading corporations. He holds numerous patents in heat transfer field in US and Canada. The DEEP coil has evolved after exhaustive testing on more than 2 dozen successive prototype samples over a period of several years. For more information on the technology and commercialization, contact Hemant D Kale, PE, Thermorise Inc., 315-416-0780 or info@thermorisecoil.com