The Design of Quiet Air-Cooled Heat Exchangers

A Paper for The Energy Resources Conservation Board

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by

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SUMMARY

Air-cooled heat exchangers are a source of plant noise. Therefore, it is important to design each unit to produce the minimum amount of noise while still meeting the thermal requirements at a reasonable cost. This paper discusses the major noise sources of an air-cooled heat exchanger, the factors affecting the noise from each source, and how the source affects the overall noise level of the air-cooled heat exchanger.

INTRODUCTION

Many industrial facilities are required to meet stringent noise requirements. These requirements are imposed to protect workers' hearing and/or to meet community ordinances. The facility designer must pay careful attention to the noise level of all industrial equipment, including air-cooled heat exchangers.

Measurements for community noise requirements are made at the plant boundary or nearest residence in the far field of the heat exchanger. The far field is defined as the region where there is a linear relationship between the sound pressure level measured and the distance from the noise source. See Figure 1.
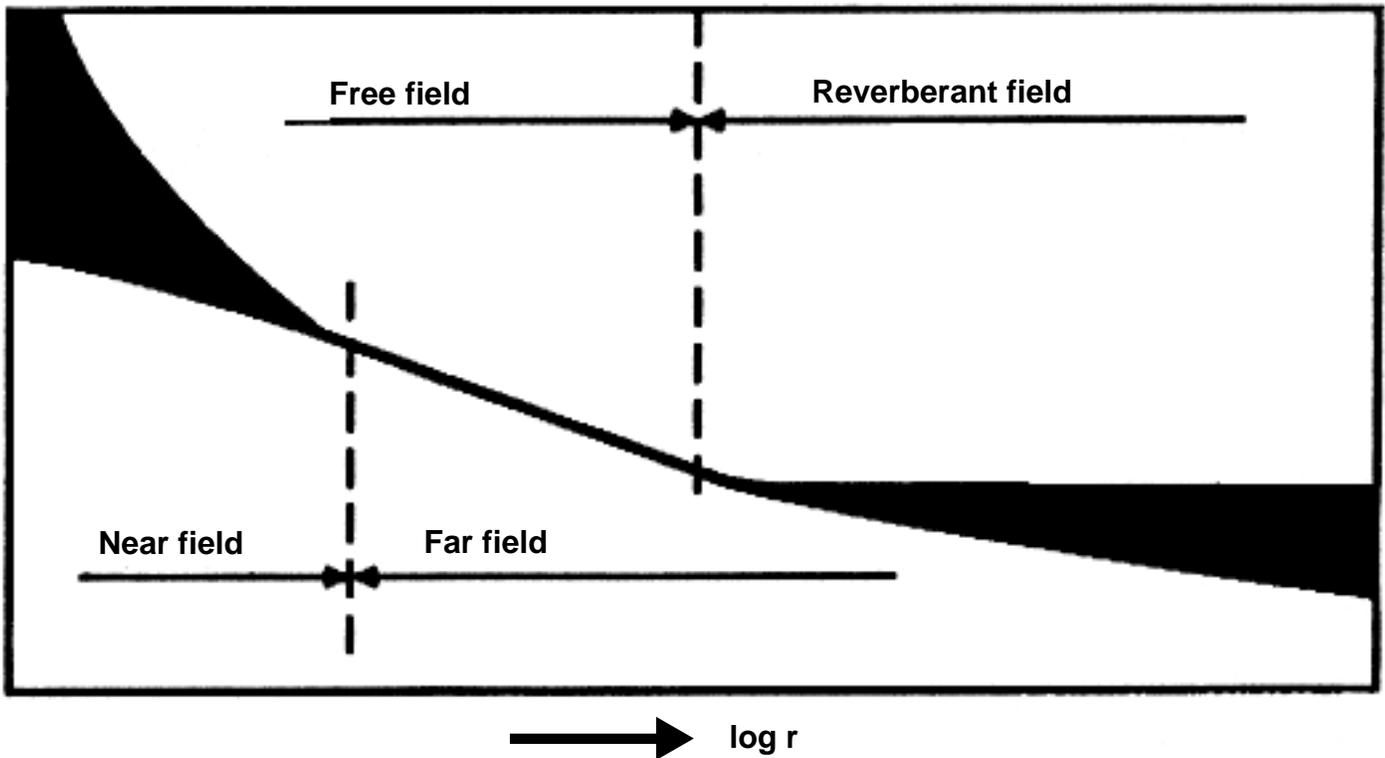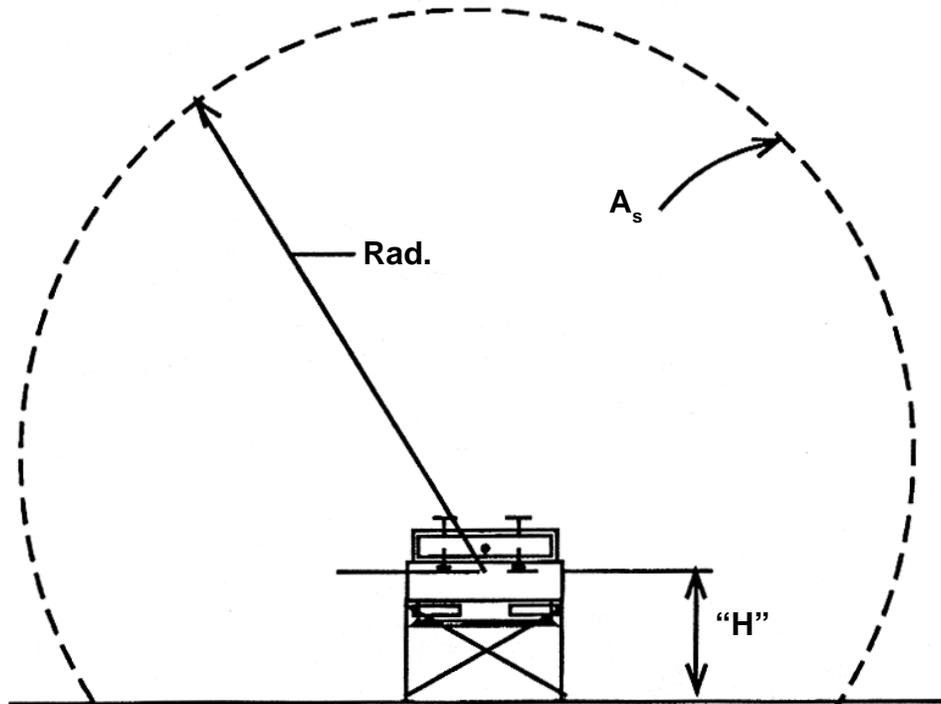

Figure 1
Near vs. Far Field

In the far field, the sound pressure level will drop 6 dB with each doubling of distance. The far field will generally begin at a distance of twice the largest machine dimension. For instance, if a heat exchanger is 16' x 20', then the far field will begin at 40' from the source. In the far field, the sound pressure level can be calculated by

$$SPL=PWL+10*\log_{10}(1/A_s)+.2 \qquad (A_s \text{ in m}^2)$$

A_s is the surface area over which noise is radiated. See Figure 2.

Figure 2
Calculating SPL in the Far Field

Noise will tend to radiate from a non-directional source uniformly in all directions. Sound pressure waves move spherically away from the source. The radius of this sphere is the distance to the measurement point. However, if there is a reflective surface impeding spherical radiation, then the radiation will become only partially spherical. In this case, the surface area also depends on the height of the noise source above the ground. In this case,

$$A_s=2\pi*r(r+h)$$

If the height goes to 0, the radiation takes on a hemispherical shape and

$$A_s=2\pi*r(r+0)=2\pi*r^2$$

In-plant noise requirements are generally in the near field of the noise source. In this region, sound pressure levels are difficult to predict because of the nonlinear relationship between sound pressure level and distance from the source. See Figure 1.

Also, noise sources that are not directional in the far field may be directional in the near field. Figure 3 shows typical sound pressure levels at 3' from the edge of an exchanger. Noise levels to the side of the heat exchanger are much lower than levels directly above and below the heat exchanger. The maximum noise level at 3' from the noise source is often specified to insure that workers will not be exposed to unacceptable noise levels. This information must be supplied in addition to Sound Power Level data since one cannot be inferred from the other.

84 dBA

71 dBA

85 dBA
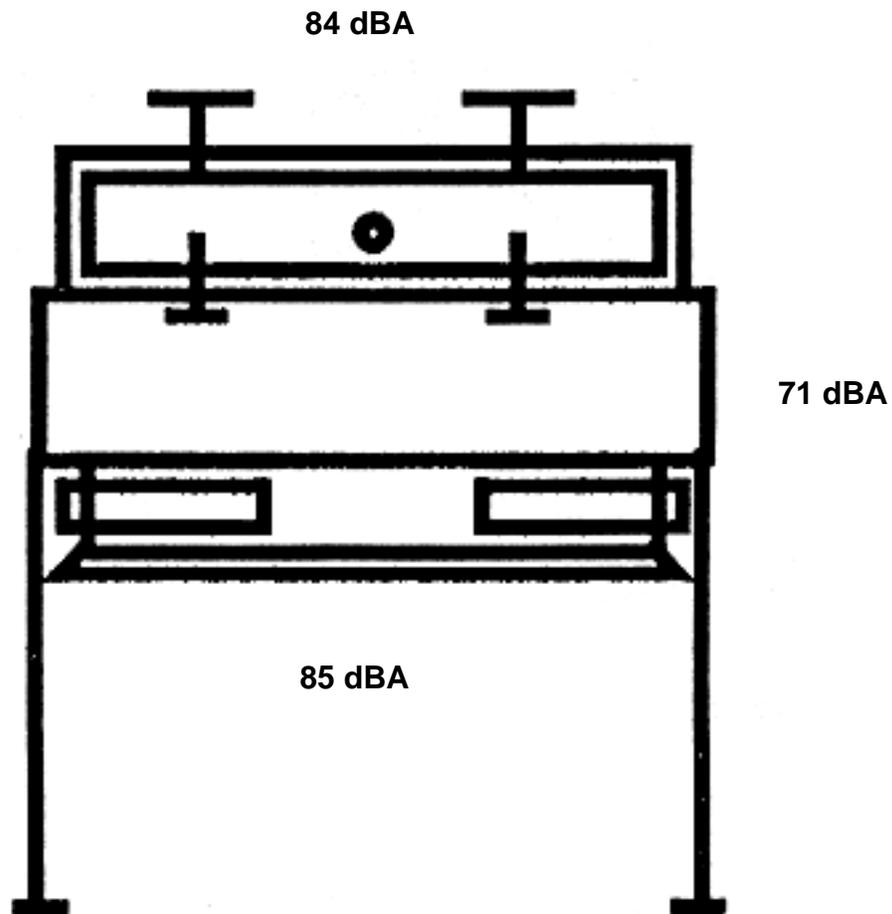
Figure 3
Sound Pressure Levels in the Near Field
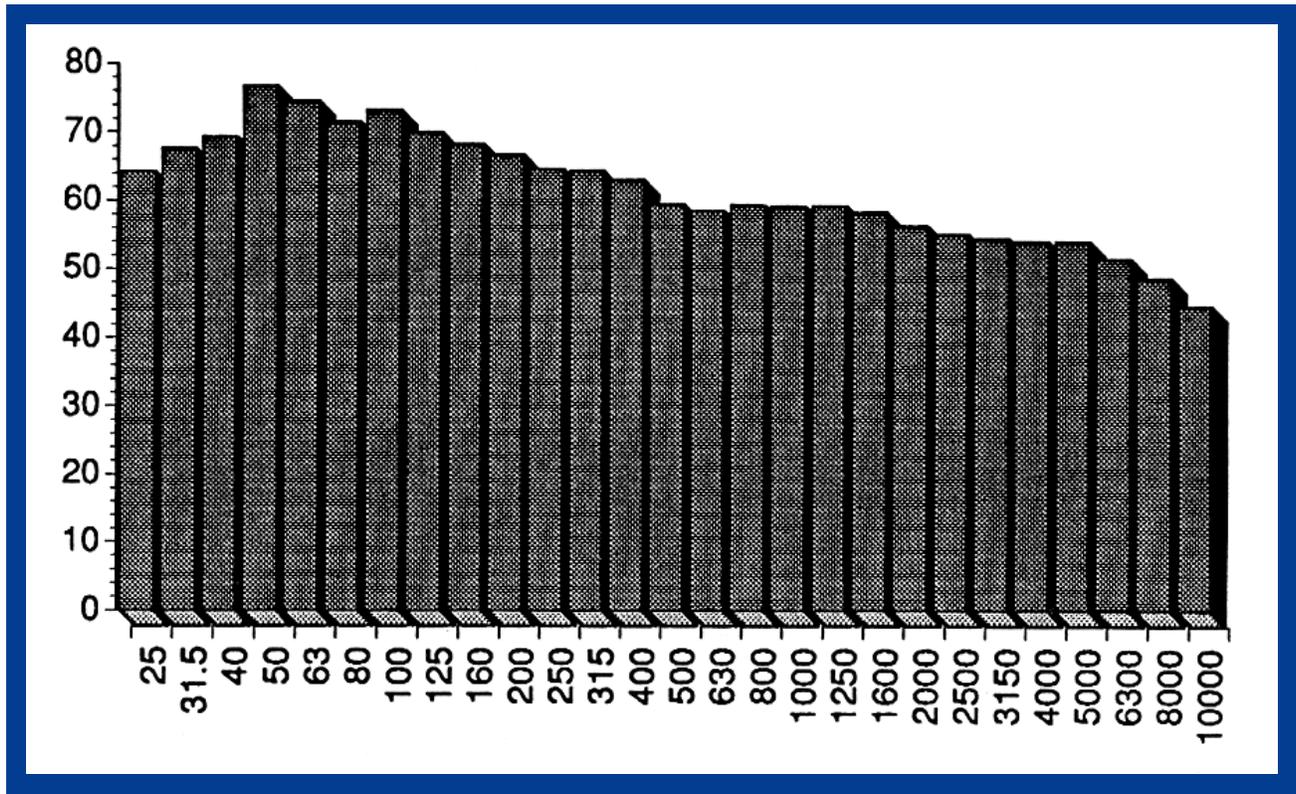**of an Air-Cooled Heat Exchanger**

NOISE FROM AN AIR-COOLED HEAT EXCHANGER

The American Petroleum Institute has issued a recommended practice for measuring noise from air-cooled heat exchangers. API RP 631M specifies a hemispherical test method with 13 measurement points. Figure 4 shows a test facility set up to perform this test. This facility is equipped with thirteen precision, permanently mounted microphones and an octave band analyzer with the ability to record Leq sound levels. This precision instrumentation and hemispherical test method give a repeatability of ± 0.1 dBA, Using this test facility and tests on customer units, we have gathered considerable data on air-cooled heat exchanger noise.

Figure 4
Noise Test Facility

Air-cooled heat exchangers have four main noise sources: fans, drives, motors, and structural vibration. Heat exchanger noise is a function of fan tip speed, input power, diameter, and pitch angle, plus factors for tip clearance, inlet flow conditions, motor noise and drive noise. A typical 1/3 octave band heat exchanger noise spectrum is shown in Figure 5 below. Note the absence of pure tones. Because heat exchanger noise is made up of noise from several sources, all at different frequencies, the noise is broad band in nature.

Figure 5
Air-Cooled Heat Exchanger Noise Spectrum

FAN NOISE

Fan noise is the greatest contributor to air-cooled heat exchanger noise. The following equation represents the noise from a standard heat exchanger fan:

$PWL=C+30*\log_{10}(TipSpeed/1000)+10*\log_{10}(hp)-5*\log_{10}(Dia.) + f$(pitch angle, tip clearance, inlet flow conditions)

Blade design is the primary factor affecting fan noise. The blade design determines the pressure capability of the blade. Since the pressure is proportional to the fan speed squared, added pressure capability means a fan can run slower and do the same work. From the equation above, the reduction in noise due to fan speed will be $30*\log_{10}(\text{TipSpeed2/TipSpeed1})$. In addition, there are noise reductions inherent to the blade design. The following is an example of how different blade designs can generate very different noise levels.

This example compares three types of blades: straight chord, tapered chord and low noise. Typical straight chord fan blades are made of extruded aluminum. These blades have the lowest pressure capability of blades used in air-cooled heat exchangers.

Standard tapered chord blades are made of fiberglass reinforced plastic molded with taper and twist in the airfoil. The tangential velocity of the blade is much greater at the tip than it is at the inboard sections. The work an airfoil can do is related to its angle of attack and its tangential velocity in the medium. To compensate for the lower tangential velocity, the twist (angle of attack) and chord width are increased toward the inboard section of the blade. The purpose of this is to maximize work done at all points along the blade. The result is a blade with good pressure capability (1.3 X straight chord blade) and high efficiency which is useful for meeting most noise requirements.

Low noise blades are similar to standard tapered blades with a tapered, twisted airfoil, but with a much wider chord. These blades have twice the pressure capability of standard tapered blades (2.6 x straight chord blades). One of the most effective methods of air cooler noise control is to utilize low noise fan blades that have a very high-pressure capability and move the same air at lower tip speeds, therefore reducing the noise generated by the fan.

The example shown in Figure 6 is an actual air-cooled heat exchanger installation with 0.718" wg static pressure and 126,738 cubic feet per minute airflow. A straight chord fan must turn at 9000 FPM tip speed to do the required work. The Sound Power Level (PWL) from this fan is 96 dBA. A standard tapered fan with taper and twist in the airfoil can turn 8000 FPM to do the required work with a PWL of 93.3. A low noise fan with maximum pressure capability can turn 6600 FPM with a PWL of 88.3. The low noise fan generates 7.7 dBA less noise than the straight chord fan.

COMPARISON OF FAN NOISE

• Pressure varies with Fan Speed [2]
• Fan speed has greatest effect on noise

Aluminum Fan (straight chord)	Standard Hudson Fan (tapered chord)	Low Noise Hudson Fan (maximum pressure capability)
Lowest pressure capability	Pressure = 1.3 x Aluminum Fan	Pressure = 2.6 x Aluminum
9000 FPM	8000 FPM	6600 FPM
96 dBA	93.3 dBA	88.3 dBA

• Noise reduction possible with Hudson Low Noise Fans: 7.7 dBA

Based on installation in an air cooler requiring .718" static pressure and 126,738 ft3/min airflow

Figure 6
Comparison of Noise from Different Blade Designs

Inlet flow conditions, tip clearance and recirculation at the fan hub can also affect fan noise. Inlet bells should be smooth and rounded, and obstacles in the air stream should be minimized to promote non-turbulent flow into the fan. Tip clearance and recirculation at the fan hub affect efficiency. As input power increases due to lost efficiency, noise increases by $10* \log_{10} (HP2/HP1)$. Seal discs should always be used to prevent losses at the hub. A tip seal may be used if tip clearance is excessive. Turbulence, lost efficiency and blade design may affect the overall noise level at the air-cooled heat exchanger up to 8 dBA.

MOTOR NOISE

The effect of motor noise is much less than fan noise. Motors can affect the noise level of the air-cooled heat exchanger by 1 dBA. Motor noise can be reduced by using a premium efficiency motor instead of a standard efficiency motor.

DRIVE NOISE

Drive noise can contribute 1-3 dBA to the overall noise of the air-cooled heat exchanger.

Gears emit noise at the gear mesh frequency, the frequency at which the teeth of the gear sprockets come together. This is a mid-to-high frequency noise, generally 125-500 Hz depending on the gear ratio. There are significant differences between manufacturers in gear noise due to differences in machining of the teeth. In general, double reduction gears are quieter than single reduction gears, and worm gears are quieter than both of these other designs.

HTD belt noise is generated as the air is pushed out of the belt tooth valleys as the sprocket teeth engage. The sound occurs at the frequency at which the tooth is engaged, the sprocket speed times the number of teeth on the sprocket. This is generally high-frequency noise in the range of 1 kHz – 4kHz. Most manufacturers offer reduced noise models which are significantly quieter than standard models.

NOISE FROM STRUCTURAL VIBRATION

Periodic forces from rotating equipment can drive resonances in the structure of the air-cooled heat exchanger. Vibrations in panels can produce low-frequency noise. The problem can and should be eliminated in the design stage by analyzing the structure for its resonant frequency and making sure the fan and motor do not operate near this frequency.

CONCLUSION

In the case of critical noise applications, low noise fans and quiet heart exchanger design are essential to success. It is possible, through careful design, to reduce noise and make a substantial impact on overall plant noise. If an existing installation is a problem, many changes can still be made to reduce the noise. An air side evaluation will reveal where the fan is operating relative to the design conditions. A noise survey can identify the frequency where the noise problem occurs. This information can be used to assess which components should be modified or replaced to improve system efficiency and reduce noise levels.

The Evolution of Quiet Air-Cooled Heat Exchanger Fans
Presentation Summary – November 9, 1993

NOISE SOURCES

Four main noise sources of Air-Cooled Heat Exchangers
- Fans
- Drives
- Motors
- Induced Structural Vibration

Fans are largest contributor to overall noise level

- blade design
    - tip speed
    - required fan horsepower

Motors
- varies between manufacturers and standard and premium efficiency

Drives
- gears generally noisier than belts
- gear noise at mesh frequency
- belt noise is high frequency

Induced Structural Vibration
- panels excited by low frequency sound waves causing resonance
- obstacles such as structural supports induce vibration due to blade passing frequency harmonics

Other Sources
- bundle fouling
- excessive backflow through excessive fan blade tip clearances and through the hub portion of the fan assembly causing turbulence, loss of efficiency

SOLUTIONS

Fans
- high efficiency fan blades capable of moving the same air at lower tip speeds with a very high pressure ability

Low Noise Motors and Drives

Backflow Prevention Devices

Other – Berms, Silencers, Interactive Feed Back Systems

Air Side Evaluation on Site Measurement and Performance Analysis Techniques
- Air Flow Rate
- Motor Power Consumption
- Static Pressure Losses
- Inlet/Outlet Temperatures
- Fan Efficiency

COMPARISON OF FAN NOISE

Pressure varies with Fan Speed^2

Fan speed has greatest effect on noise

Aluminum Fan
(straight chord)
Lowest pressure capability
9000 FPM
96 dBA

Standard Hudson Fan
(tapered chord)
Pressure = 1.3 x Aluminum Fan
8000 FPM
93.3 dBA

Low Noise Hudson Fan
(maximum pressure capability)
Pressure = 2.6 x Aluminum
6600 FPM
88.3 dBA

Noise reduction possible with Hudson Low Noise Fans: 7.7 dBA

Based on installation in an air cooler requiring .718" static pressure and 126,738 ft3/min airflow

BASIC NOISE CALCULATION

HUDSON AXIAL FLOW FANS

PWL (dB A) =   Constant

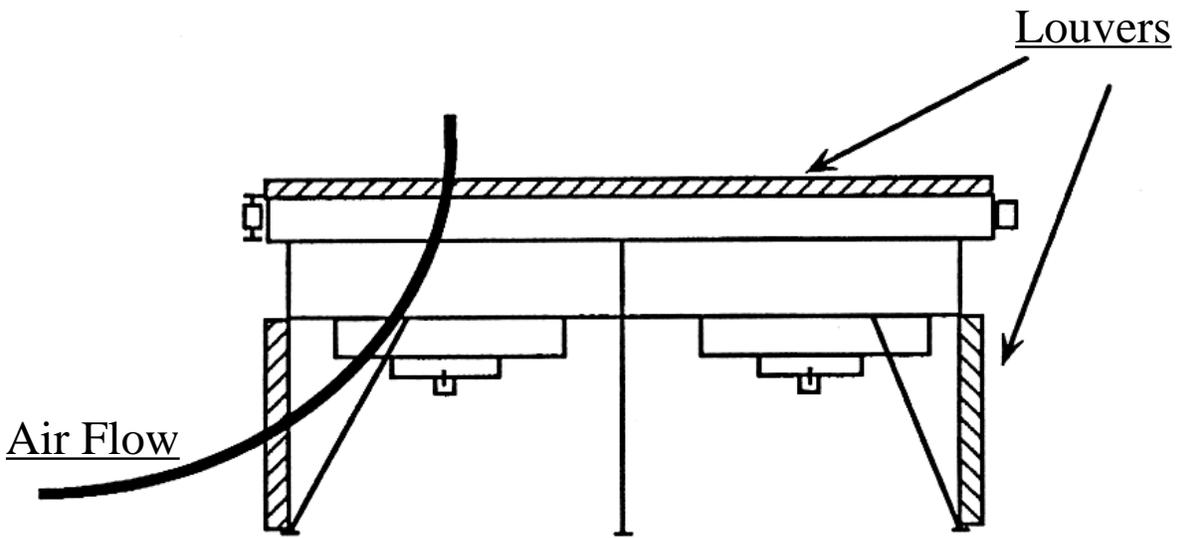$$+ \; 30 \log \frac{\text{Tip Speed}}{1000}$$

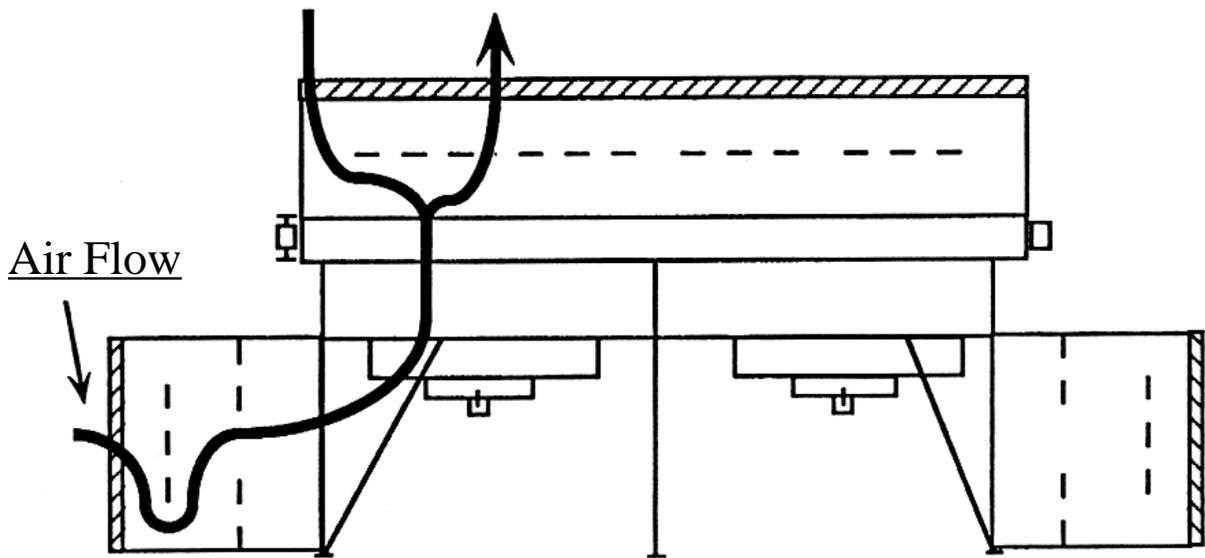$$+ \; 10 \log \text{Horsepower}$$

$$- \; 5 \log \text{Fan Diameter}$$

Pitch Angle

Inlet Conditions

Tip Clearance
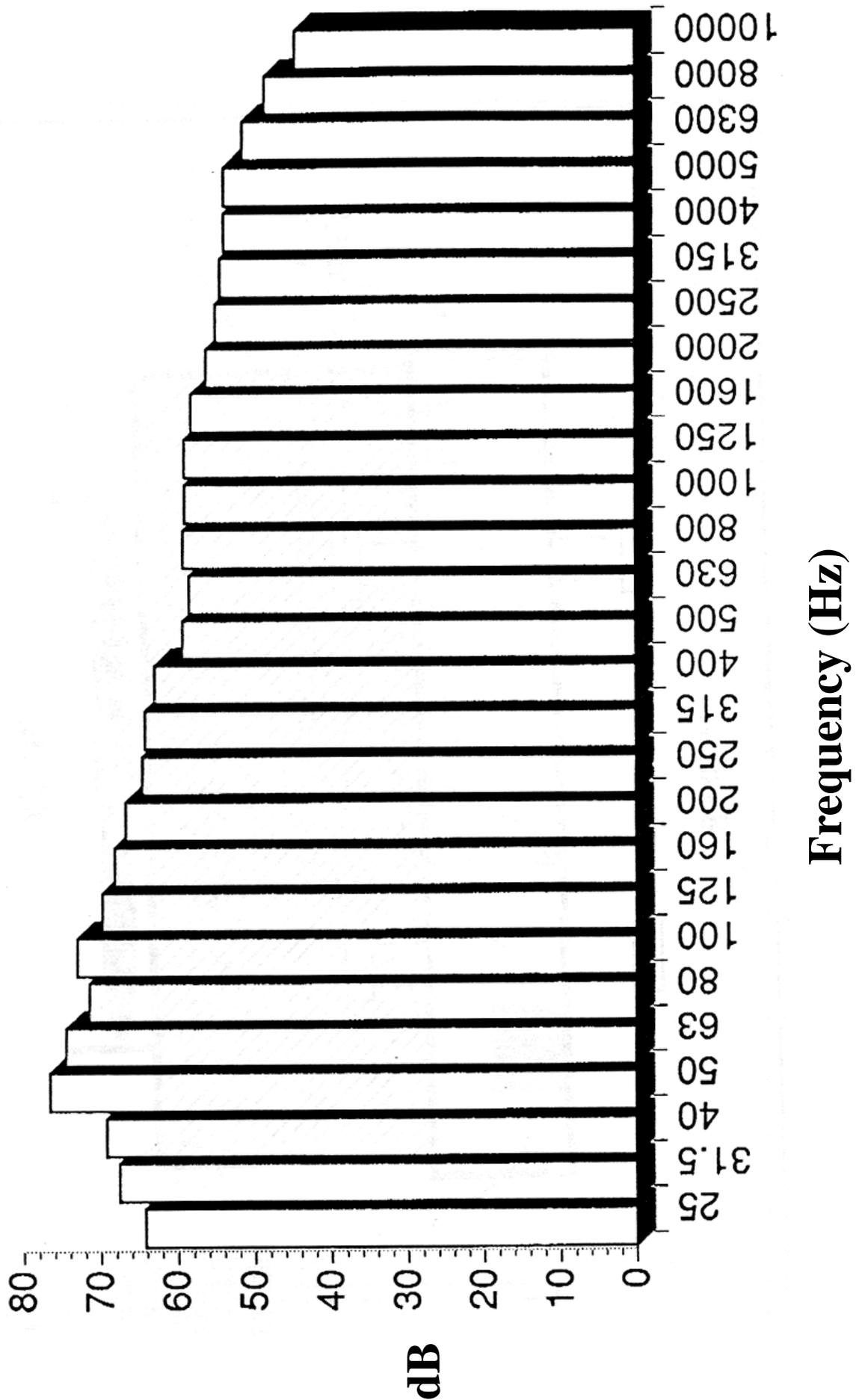
Conventional Fin-Fan® Cooler

Baffled Fin-Fan® Cooler

BAFFLES = STATIC LOSSES = INCREASED HP

TYPICAL AIR COOLER NOISE SPECTRUM
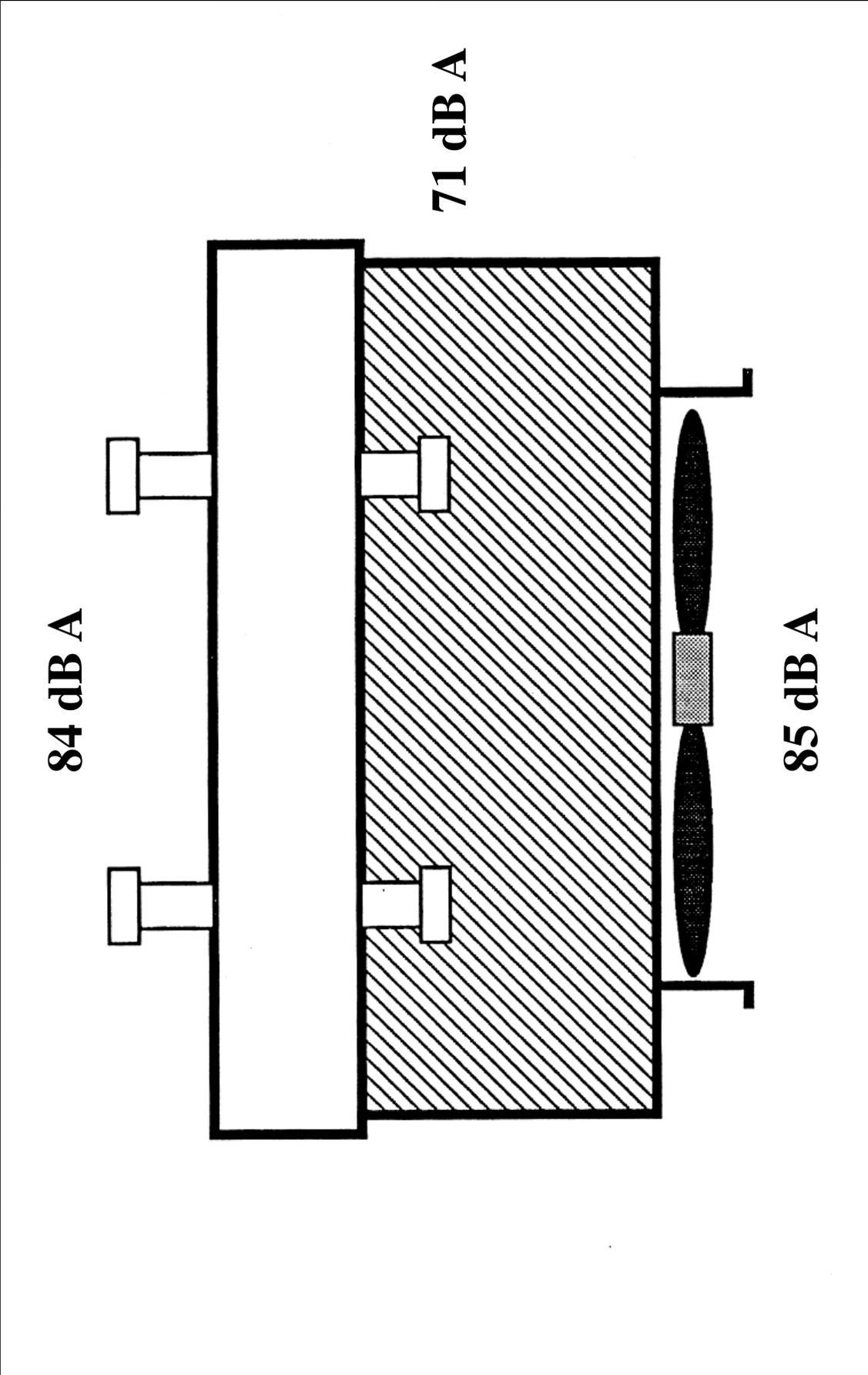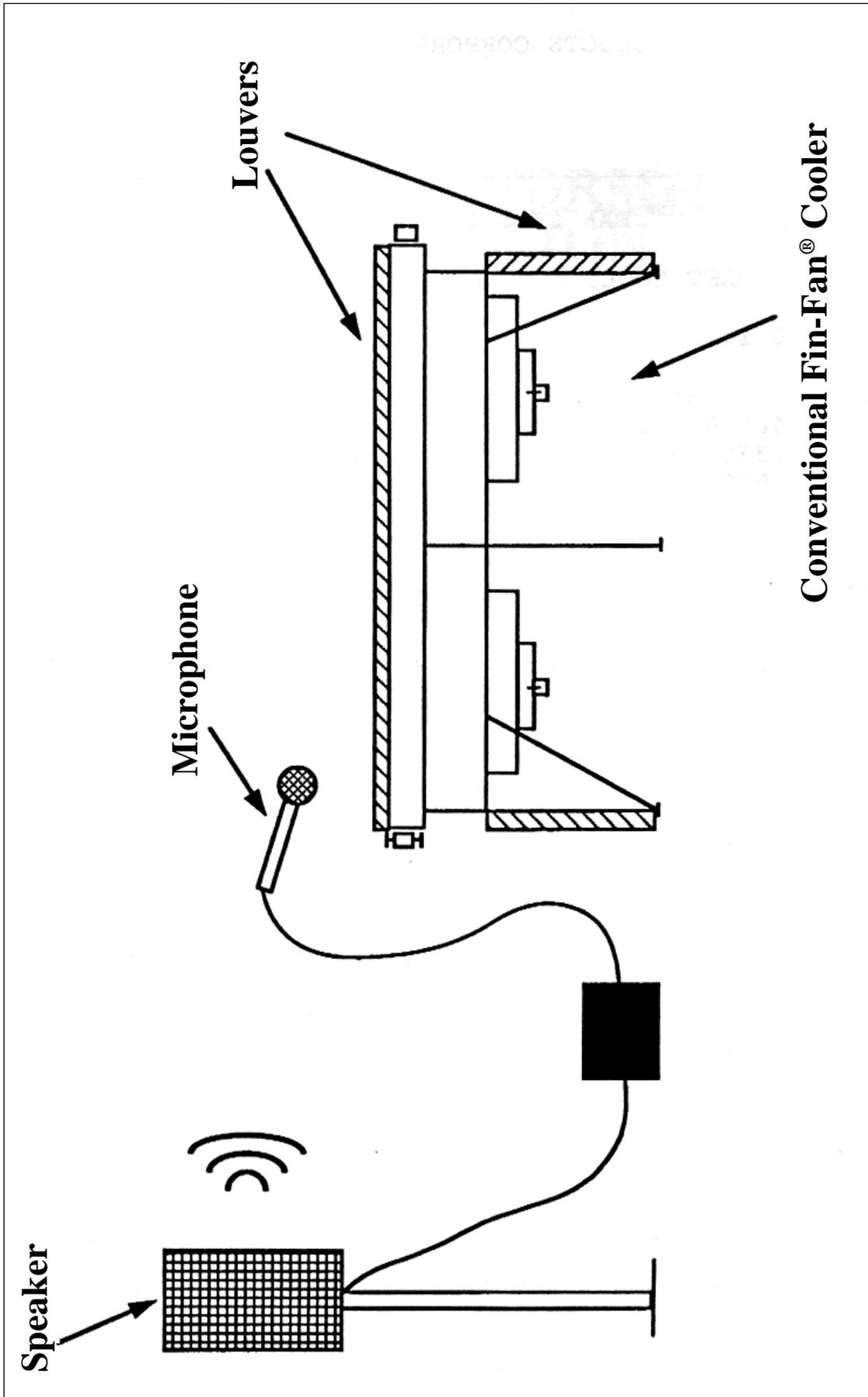
dB (vertical axis): 0, 10, 20, 30, 40, 50, 60, 70, 80

Frequency (Hz) (horizontal axis): 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000, 10000

84 dB A

71 dB A

85 dB A

PROPOSAL INFORMATION

Prepared By   : HUDSON PRODUCTS CORPORATION
Preparer   : RCM   Inquiry Number :
Customer Name : EXAMPLE   Item Number   :
Job Number   :   Run Date   : 01/19/94

FAN SELECTION INPUT DATA

Fan Use : INDUCED DRAFT COOLING TOWER

Fan Diameter   : 30 ft.   Fan Speed   : 127.0 RPM
Blade Type   : H   Max Tip Speed   : 12000 ft/min
No. of Blades :   Venturi Height   :
Airflow   : 1400000 cu ft/min   Blade Pass Frq Marg   :
Static Press. : 0.375 inches wg   No. of Support Beams   :
Air Density   : 0.0750 lb/ft^3   Sound Power Level/Fan :
Temp. at Fan   :   Inlet Bell   : Rounded, R/D=0.1
Elevation   :   Optimization   : HP

FAN SELECTION RESULTS

Recommended Fan Selection : 30H-9   List Price : $12806.00
Hub Model   :

Fan Diameter   : 30 ft.   First Mode RF   : 4.40 Hz
Blade Type   : H   Second Mode RF   : 14.60 Hz
No. of Blades   : 9   Minimum RF Margin   : 23.36 %
Pitch Angle   : 14.5 Deg.   Actual Total Pressure : 0.651 in. wg
Brake HP   : 218.5 HP   Velocity Pressure   : 0.276 in. wg
BHP Per Blade   : 24.3 HP   Velocity Recovery   : 0.000 in. wg
Max BHP Per Blade : 26.0 HP   Blade Pass Frequency : 19.1 Hz
Fan Speed   : 127.0 RPM   Beam Pass Frequency   : 0.0 Hz
Tip Speed   : 11969 ft/min   Airflow Mass   : 6300000 lbs/hr
Total Efficiency : 65.6 %   Air Density   : 0.0750 lb/ft^3
Static Efficiency : 37.8 %   WR^2   : 43033 lb-ft^2
Gross Weight   : 1888 lbs   Total Thrust Load   : 4135.19 lbs

Noise Sound Power Level (PWL) per Fan : 105.3 dbA

Octave Bands (Hz) :	31.5	63	125	250	500	1K	2K	4K	8K
PWL (Decibals) :	107.3	110.4	109.2	106.2	100.7	100.3	95.1	92.6	85.4

Hudson Products fan ratings are the result of tests run under ideal conditions.
Since actual conditions will vary and are beyond Hudson Products' control,
Hudson Products makes no warranties or guarantees concerning fan performance,
and all such warranties or guarantees, including merchantability and fitness
for a particular purpose, are disclaimed.
          ** Prices subject to change without prior notice **

AIR SIDE PERFORMANCE EVALUATION

- Air Flow Rate

- Motor Power Consumption

- Static Pressure Losses

- Inlet / Outlet Air Temperatures

- Fan Efficiency

HUDSON PRODUCTS CORPORATION has been designing heat transfer products for over 50 years. We are a wholly owned subsidiary of McDermott International, Inc.

Hudson designs and manufactures axial flow fans and heat transfer products. Our products are used worldwide in commercial, utility and industrial installations, serving the petroleum, chemical, gas processing, pulp and paper, and electric utility industries. Our products include air-cooled heat exchangers, air-cooled vacuum steam condensers, air preheaters, axial flow fans, fan control systems, heat pipe heaters and gas/liquid separators.

Our main office is in Houston, Texas, where designers, engineers, draftsmen, and computer specialists combine their efforts to design the best heat transfer equipment available in the world today.

Production facilities are 35 miles southwest of Houston, where over 90 percent of all components in Hudson's products are manufactured.

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