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Design of a System to Control the Noise of Dry Fluid Coolers

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Abstract:

The today's socio-physical needs demand for conducive acoustical environment for living & working, than never before. In the industrial areas, awareness regarding the noise reduction & control is increasing day by day. In this paper, study has been carried out on barrier design to reduce the noise level at the receiver, for any type of heat exchanger. In this paper, noise is treated along the path. The paper includes mathematical calculations for noise in Dry Fluid Coolers with and barrier. Barrier design procedure includes material of barrier, height, width, length of barrier, source and receiver distance from barrier, source and receiver height, Fresnel number, path length difference etc. Considering all above the parameters and studying the combinations of these parameters more concentration is given on material of barrier, height of barrier and path length difference (δ). So this paper includes details studies of these three parameters, these parameters contribute more for noise reduction at the receiver position. Properly selected parameters will give good noise reduction. A case study is presented in this study where barrier design results in nearly 15 dB noise reduction.

Keywords: Dry Fluid Cooler, Fresnel Number, Barrier, Heat Exchanger, Sound, Noise

Nomenclature

A= distance from the noise source to the top of the barrier (m)
B= distance from the top of the barrier to the receiver (m)
d = direct path of noise between source and receiver. (m)
δ = the difference between the geometrical distance from source to receiver and the shortest path from the source to the top of the wall then to the receiver. (m)
b = height of the barrier (m)

a = width of barrier (m)
h = thickness of barrier (m)
x = distance between source and the barrier. (m)
y = distance between barrier and receiver. (m)
Q = volumetric flow rate through the fan (cfm)
P = pressure rise through the fan (in H_2O)
Lp = sound pressure level (dB)
Lw = sound power in (dB)
DI = Directivity index
r = distance between noise source and receiver in m.
Lp, i= sound pressure level calculated for particular octave bands.
C_L = Longitudinal Speed of Sound (m/sec)
ρ_w= Material Density (kg/m^3)
f = Band Frequency (Hz)
Z = Characteristic Impedance
σ = Poison's Ratio
E = Young's Modulus (MPa)
a_b= barrier coefficient
a_t= sound power transmission coefficient for the barrier wall.
N= Fresnel number,
f_B = The blade pass frequency

1. Introduction:

A Dry Fluid Coolers is a device used for transfer of thermal energy between two or more fluids or between a solid surface & a fluid. The nature of application of Dry Fluid Coolers leads to its installation in nearest vicinity of buildings; may it be commercial or no commercial. Generally Fin tube heat exchangers are deployed besides the building or on roofs to serve the purpose. A considerable level of noise is generated by the moving parts of the Dry Fluid Coolers, especially by its fan. Now-a-days, production of such noise has become a severe problem because these instruments & appliances need to be installed in the places where people inhabit, work &relax. Therefore, increasing concern about noise from mechanical devices & its consequences led to increasing demand for quieter Dry Fluid Coolers & it has become a necessary requirement for Dry Fluid Coolers.

1. 1 Noise:

'Sound' is a propagating vibratory disturbance or wave in an elastic medium (solid, liquid or gas). Whereas 'Noise' is defined as any unwanted or undesirable sound. Therefore, virtually any major component of a heat exchangers/HVAC system is a potential source of noise, e. g. fans in tube fin heat exchangers. [6]

1. 2 Types of noise in Dry Fluid Coolers:

Periodic noise' is the noise that has discrete frequency noise emissions related to the rotations of the blades of fans, it is a noise related to some defects in the design of the fan or during the process of construction. The broadband noise is a kind of noise that is produced because the fans operate with air which is entirely governed by aerodynamic conditions. [2]

1. 3 Fan as a Source Of noise creation in Dry Fluid Coolers:

Turbulence generated by 'fan supports' or other upstream obstructions of heat exchangers leads to ingestion of turbulence in the main air flow.

***Fan Unbalance*:**

Unbalance is one of the leading causes of noise in rotating machinery.

***Motor Noise*:**

Noise of magnetic origin may be radiated by the fan if the impeller is mounted directly on the motor shaft. [7]

1. 4 Need of noise control in Dry Fluid Coolers:

Noise beyond certain levels may lead to, 1) Increase in stress levels, 2) loss of concentration, 3) loss of hearing capacity. Hence, there is profound need to maintain noise below certain level. Also low noise heat exchangers are beneficial for the industries to increase their market value.

2. Barriers-As a Method for Noise Reduction in Dry Fluid Coolers

One of the best option is to reduce the noise along the path. This leads to two possibilities-place sound-reducing barriers between the source. Considering cost & space implications, the best solution to reduce the noise is use of barrier. [2]

A sound barrier is usually a solid material which, by virtue of its mass, acts as an acoustical reflector, interrupting the path of a sound wave. When a noise barrier is located between a noise source and a receiver, the sound attenuation occurs behind the barrier.

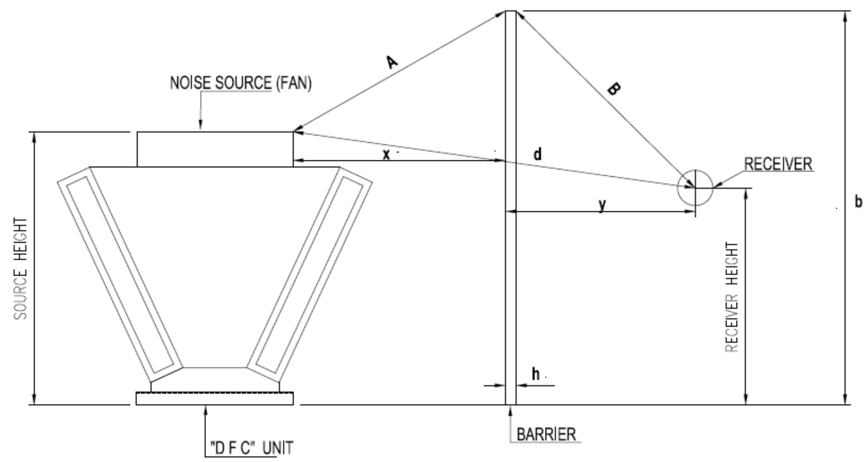

Fig. No. 1: Schematic Representation of Parameters of Barrier Design

3. Barrier Design:

3. 1Objective of Barrier Design:

The quantified objective of barrier design is to reduce Noise from existing level of 85db to below 70db by holding constant cooling capacity, fan design, Space constraints & location of receiver& source.

3. 2 Methodology followed for barrier design:

3. 2. 1 Mathematical procedure to calculate noise levels: **[3]**

In this paper for calculating sound level data I used Wing Fan Selection Software. Software consist of different parameters like rotation speed, air flow, static pressure, tip clearance, diameter of fan, blade angle etc. On the basic of these input values software will directly give sound level data which I used for further calculation. [8]

Operating points for Dry Fluid Cooler:-Source and receiver distance:-2 m, Air inlet temperature:-38 °C, Air outlet temperature:-50. 64 °C, Face Velocity:-3. 5 m/sec, Fin spacing:-10 fpi, Air flow (Q):-26, 930 CFM, Static pressure (P):-12. 71 m^3/sec OR 0. 63 in H_2O, Density:-1. 134 kg/m^3, Fan diameter:-1100 mm, Speed of fan:-960 rpm, Number of fan blades:-8, Heat exchanger height and width:-2 m

Table No. 1: Sound Power & Sound Pressure Data

Frequency	Lw	LwA	Lp	LpA
63	88	62	74	48
125	95	79	81	65
250	91	82	77	68
500	90	87	76	73
1000	88	88	74	74
2000	85	86	71	72
4000	82	83	68	69
8000	79	78	65	64
Addition	99	93	85	79

The overall sound pressure level i. e. Addition can be calculated by using above value of Lp,

Overall L_P=10 log$\{\sum_{i=1}^{n} 10^{L_{p,i}/10}\}$ dB

Lp= 10 log $\{10^{74/10} + 10^{81/10} + 10^{77/10} + 10^{76/10} + 10^{74/10} + 10^{71/10} + 10^{68/10} + 10^{65/10}\}$ = 85 dB

3. 2. 2 Mathematical procedure to calculate noise levels by using Barrier:[Randall F. Barron et al, 2003]

First calculate the resonant frequency (F_{11}),

$$F_{11} = 0.\ 4534 * C_L * h \left(\frac{1}{a^2} + \frac{1}{b^2}\right) \text{ Hz} \quad (1)$$

Then, Calculate Specific Mass,
$M_S = (\rho_W * h)$ (Kg/m^3) (2)
Then, Calculate Critical frequency,
$$f_c = \frac{M_S f_c}{M_s} in Hz \quad (3)$$

From f11and fc we have to decide the frequency region.

There are three general regions of behavior for the wall or panel & they are, (a) Region I: stiffness-controlled region, (b) Region II: mass-controlled region, (c) Region III: wave-coincidence region (damping-controlled region)

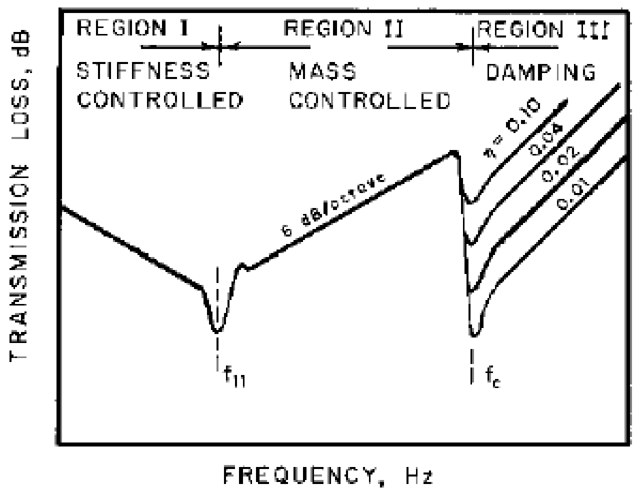

Fig. No. 2: Variation of Transmission Loss with Frequency

Techniques for prediction of the transmission loss for each of these regions are:-

(A) If the frequency lies between first region i. e. Stiffness Controlled Region then,

$$i)\ C_S = \frac{768(1-\sigma^2)}{\pi^8 E h^3 (\frac{1}{a^2} + \frac{1}{b^2})^2}$$

$$ii)\ find\ K_S = 4\pi f Z_1 C_S$$

iii) Find, Sound power transmission coefficient,

$$a_t = K_S^2 \ln(1 + K_S^{-2})$$

*iv)*Transmission Loss (TL)= $10\log\left(\frac{1}{a_t}\right)$

(B) If the frequency lies between second region i. e. Mass Control Region then,
For frequencies higher than the first resonant frequency, the transmission loss of the panel is controlled by the mass of the panel and is independent of the stiffness of the panel.

Then, transmission loss can be calculated by,

$$\frac{1}{a_{tn}} = 1 + (\frac{\pi f M_S}{Z_1})^2$$

$$TL_n = 10\log(\frac{1}{a_{tn}})$$

$$TL = TL_n - 5$$

(C) If the frequency lies between third region i. e. Damping Control Region then,
For frequencies above the critical frequency, the transmission loss is strongly dependent on the frequency of the incident sound waves and the internal damping of the panel material.

$$i) TL = TL_n(f_c) + 10\log(\eta) + 33.22\log\left(\frac{f}{f_c}\right) - 5.7$$

$$ii)\ TL_n(f_c) = 10\log\left(1 + (\frac{\pi M_S f_c}{\rho_1 c_1})^2\right)$$

3. 2. 3 Sound pressure level calculation:
For transmission of sound across a barrier located outdoors, the following expression has been developed for the sound pressure level Lp at the receiver position due to a point noise source having a sound power level LW on the opposite side of the barrier.

$$L_P = L_W + DI - 20\log(A + B) - 10\log\left(\frac{1}{a_b + a_t}\right) - 10.9 \qquad 4)$$

$$N = \frac{2f}{c}(A + B - d) \qquad 5)$$

$$a_b = \frac{tanh^2(\sqrt{2\pi N})}{2\pi N * \pi} \ (N<12.7)$$

$$= 0.004 \ (N \geq 12.7) \qquad 6)$$

$$a_t = 10^{-TL/10} \qquad 7)$$

Using above mathematical procedure we can calculate the sound pressure level for eight octave bands. But it is very lengthy& cumbersome procedure for calculation because this calculation procedure comprises of many parameters which are considered as a input parameters like height, width, thickness of barrier, receiver and source height, material selection, path length difference, distance of barrier from noise source and receiver etc.

After calculating transmission loss, the next step is to calculate the value of sound pressure (Lp). For calculating Lp values, it is required to find out some parameters like N, a_b, a_t. After calculating these values it will directly give the value of sound pressure (Lp).

***4.* Calculation of Noise Levels for Dry Fluid Coolers with barrier:**
The Factors (or control factors) are the design parameters of a concept or technology that need to be optimized. The objective is to select the control factor levels that minimize the effect of noise factors on the response. For all the factors that are required to be considered in barrier design, diff. levels were selected. These levels are

supposed to be bold higher& lower values of parameter at which barrier will perform its function. A pilot study was conducted for deciding these levels.

All dimensions are in meter (m)

1) Material = Aluminum, Steel
Source Height = 1. 75, 2
x = 0. 25, 0. 5
y = 0. 25, 0. 5
a = 2. 25, 2. 5, 2. 75
b = 2. 5, 2. 75, 3
h = 0. 0015, 0. 002, 0. 0025
Receiver Height = 0. 5, 0. 75, 1

2) Material = Plywood, Steel
Source Height:-1. 75, 2
x = 0. 25, 0. 5
y = 0. 25, 0. 5
a = 2. 25, 2. 5, 2. 75
b = 2. 5, 2. 75, 3
h = 0. 015, 0. 02, 0. 025
Receiver Height = 0. 5, 0. 75, 1

Direct distance between source and receiver (d):-2 m

Then using Taguchi method, a DOE was designed for optimizing these parameters. Taguchi designs are used for robust parameter design, in which the primary goal is to find factor settings that minimize response variation. The goal is to optimize the relationship between the input and the output of the system, includes a signal factor i. e. (length, width, height, thickness, source and receiver height, source to receiver distance from barrier). Using above input parameters I have studied 72 combinations for barrier design. For every combination obtained from Taguchi design, barrier was designed & corresponding noise levels were calculated.

Results and discussion

The Noise levels reduced from 85dB to 67 dB after addition of barrier to the system. This well exceeds the expected reduction of 70dB. Hence we can say that, use of barriers can effectively reduce the noise levels.

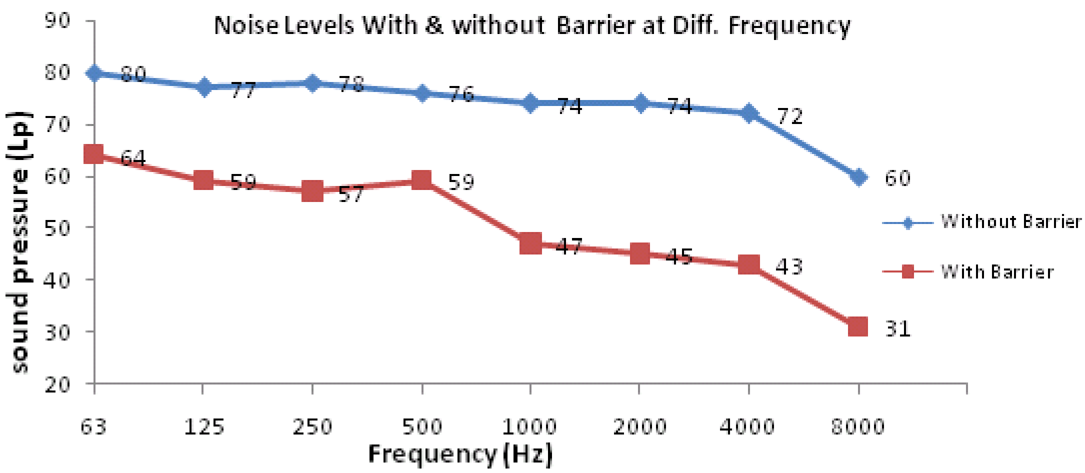

Fig. No. 3: Comparison of noise levels with & without Barriers

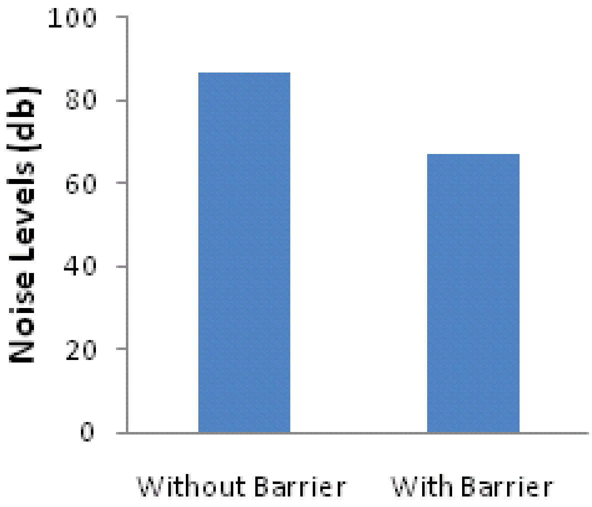

Fig. No. 4: Overall reduction of noise levels with &without barrier

So using barrier we can achieve nearly 15 dB noise reduction. After studying these results I found that there are some parameters which contribute more for noise reduction these are material of barrier height of barrier, path length difference.

Material of barrier:-Sound barrier materials are the most intuitive of all acoustic materials. There are several materials can be used for barrier but I have studied four materials (Concrete, Plywood, Aluminum, Steel) depending on the cost and the availability of the material. Graph shows that at different materials barrier gives variation in noise levels. Results shows that concrete is the best material for barrier while Aluminum shows more value of sound pressure level.

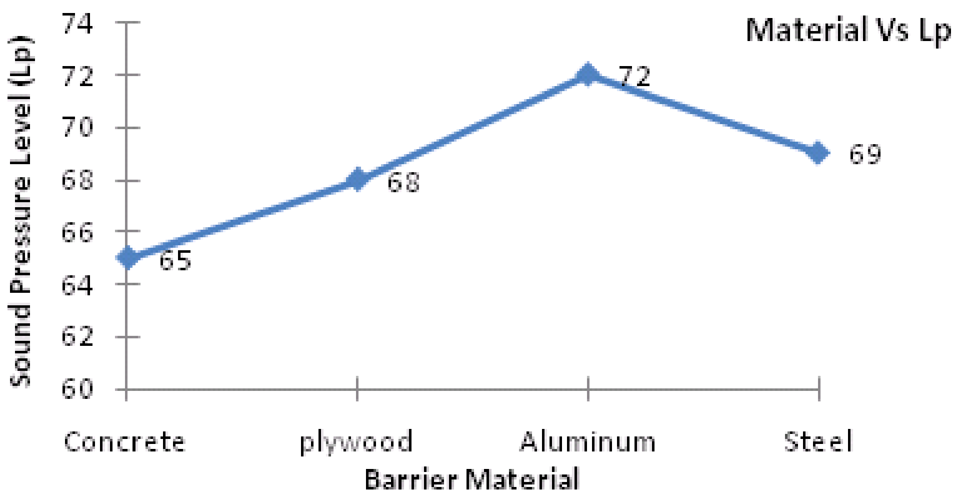

Fig. No. 5:-sound pressure level at different material

Path Length Difference:-

The difference between the geometrical distance from source to receiver and the shortest path from the source to the top of the wall then to the receiver. (m). PLD is determined from basic geometry. It is affected by barrier height, source and receiver location. Also affected by source and receiver heights. A larger PLD will result in higher attenuation. They should be built as close as possible to either the source or receiver. It is given by the formula, δ = A+B-d. The graph shows that sound pressure level will be reduced by increasing the path length difference.

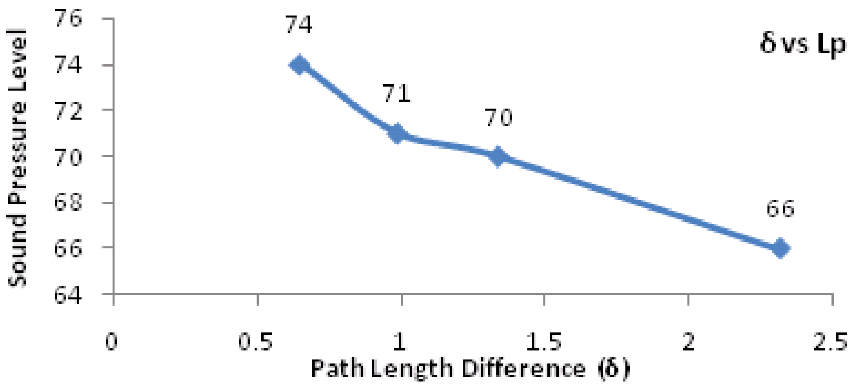

Fig. No. 6:-Path Length Difference Vs Sound Pressure Level

Barrier Height :-

Barrier height plays an important role in barrier design. As height of the barrier increases the angle between noise source and barrier and the value of A (Distance between noise source and top of the barrier) is also increases. Increase in the value of A directly affects on path length difference (δ). So the barrier height must be as high as possible. It should be more then source height.

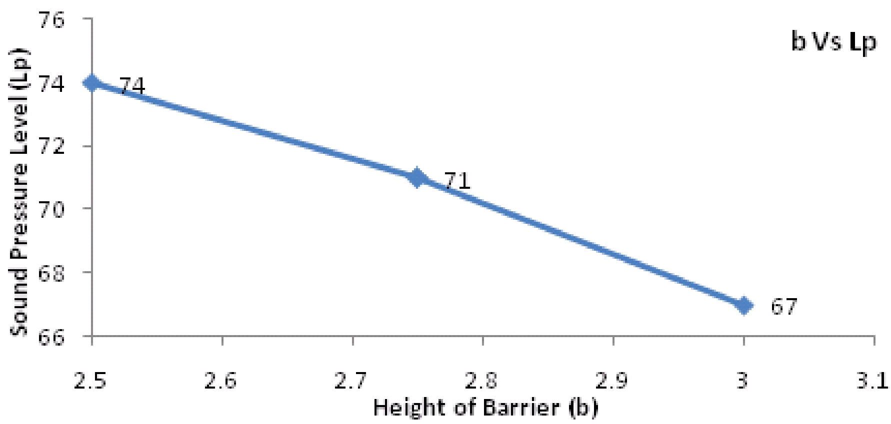

Fig. No. 7:-Height Vs Sound Pressure

Conclusion:
A careful observation & interpretation of the results for different barrier materials and all the parameters used for barrier design shows that the height of the barrier, material used for barrier and path length difference has significant influence on noise reduction. Results shows that concrete is the best material for barrier, path length difference must be as high as possible and height of the barrier must be double the source height. Therefore, one can conclude that using barrier we can achieve nearly 15 dB noise reduction at the receiver position.

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