# Prediction of Pressure Drop in Chilled Water Piping System Using Theoretical and CFD Analysis

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*Abstract* — **In the present study, three dimensional models of chilled water piping system is created using design modeler of Ansys-13. Ansys-13 fluent is used to analyses flow through chilled water pipe for pressure drop prediction. Karman-Prandtl equation is used for defining velocity profile of turbulent flow with the help of user defined function. Result obtained from CFD analysis is compared with results of 3K, 2K, ISHARE and Carrier equivalent length methods. Statistical analysis of performance based relative error has been carried out and based on that optimum analytical method for pressure drop prediction in chilled water piping is suggested.**

**Keyword- chilled water piping, 2K, 3K, Pressure drop, ISHARE, CFD analysis**

## I. INTRODUCTION

In designing air conditioning and refrigeration plant, prediction of correct pressure drop is the most important factor. Appropriate and economical selection of pump requires accurate prediction of pressure drop in chilled water piping circuit and hence calculation of pressure drop is the initial step of the pump selection process. In air conditioning plant, cold water is circulated through chiller (evaporator coil) where it reject the heat and then passed through air handling unit (AHU) where it absorbs heat. Chiller and air handling unit are connected through chilled water pipe. Length of chilled water pipe may depend up on the locations of both the units. This piping system contains different types of fittings like control valves, bends, expander, reducer, chiller coil and AHU coil.

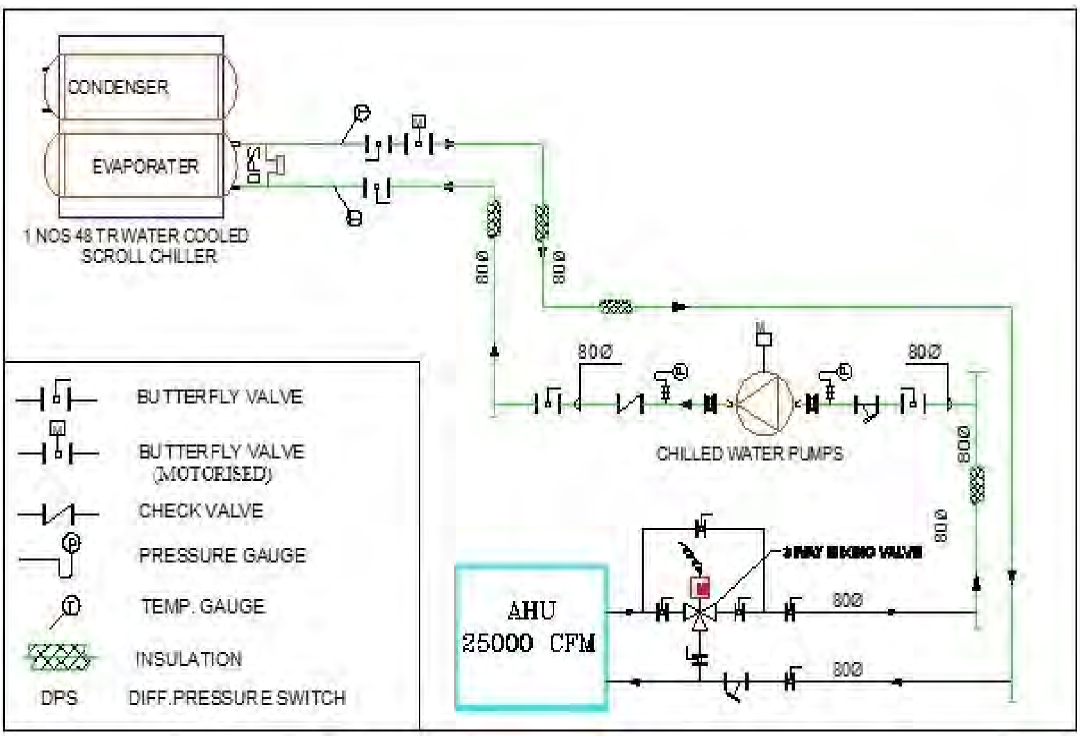


Fig. 1. Schematic diagram of chilled water piping system setup by Voltas Ltd. Pune

Schematic diagram of chilled water piping system setup by Voltas Ltd. Pune is shown in Fig. 1. Chilled water piping system contains 0.08 meter diameter (D) M.S. pipe through which water of density ($\rho$) = 998.017 kg/m$^3$

and dynamic viscosity (μ) = 0.0010129536 Ns/m$^2$ flows at rate of (Q) of 0.00789 m/sec. Whereas Fitting details are provided in table I. Pressure drop prediction in chilled water piping system is calculated in two ways: analytical methods and CFD analysis.

TABLE I
Fitting Details

| Fitting | 90° Elbow | Butterfly Valve | Motorised Butterfly Valve | Check valve | Y strainer | 3 Way Balancing Valve |
|---|---|---|---|---|---|---|
| **Abbreviation** | Elbow | BFV | MBFV | NRV | Y- St. | 3WBV |
| **Quantity (Nos.)** | 32 | 8 | 1 | 1 | 2 | 1 |

## II. PRESSURE DROP CALCULATION BY ANALYTICAL METHODS

There are different methods for calculation of pressure drop due to pipe fittings. 3K method by Darby [3][4], Equivalent length method by ISHRAE [5] and Carrier system design manual [2], 2K method by William B. Hooper [8] are analytical methods used for pressure drop prediction in chilled water piping system. In these methods pressure drop due to each fitting is calculated separately and then combined for pressure drop measurement in the entire piping system.

$$\text{Water velocity } (V) = \frac{Q}{A} = \frac{0.00789}{\frac{\Pi}{4}\times 0.08^2} = 1.569 \text{ m/sec.}$$

$$\text{Reynolds Number } (\text{Re}) = \frac{\rho\times V\times D}{\mu} = \frac{998.017\times 1.569\times 0.08}{0.0010129536} = 123663.1303 \text{ [1]}$$

Colebrook- white equation [7] is solved for friction factor (*f*) using newton raphson method with the help of C-program. Equations by Zarko and Brkic [9] are used for calculating initial value of friction factor. The calculated value of friction factor (*f*) is 0.024472165.

TABLE II
Equipment Pressure Drop Details [6]

| Equipment | Model No. | Coil Pressure Drop | Head Loss Due to Coli |
|---|---|---|---|
| 48 TR Water cooled Chiller | WCDS048DMN2X2 | 0.25 bar | 2.5556 meters |
| 25000 CFM AHU | IAW 2266 | 6 psi | 4.22889 meters |

### A. Equivalent Length Method

This method assumes that the pressure drop across the length of a pipe is same as it occurs in the fitting. Thus these fittings can be replaced by simple pipe of particular lengths which has a same pressure drop. Pressure drop calculations by equivalent length method are carried out using equation given below. Where $h_f$ is head loss due to friction.

$$h_f = f * \frac{V^2}{2g} * \sum\left[\frac{L_e}{D}\right] \tag{1}$$

TABLE IIII
Equivalent Length of Fittings by ISHARE [5] and Carrier System Design Manual [2]

| Fitting | BFV | MBFV | NRV | Y-St. | 3WBV | Elbow |
|---|---|---|---|---|---|---|
| Equivalent length ($L_e$) in Meter by ISHARE standard | 1.00 | 1.00 | 9.10 | - | 26.00 | 1.50 |
| Equivalent length ($L_e$) in Meter by Carrier System Design Manual | 0.98 | 0.98 | 9.14 | 12.80 | 25.60 | 1.52 |

#### 1) Head loss due to friction by Carrier System Design Manual [2]

$$(h_f) = 0.024472165\times\frac{1.569^2}{2\times 9.81}\times\left[\frac{(0.98\times 8)+0.98+9.14+(12.8\times 2)+25.6+(1.52\times 32)+104}{0.08}\right] = 8.5132 \text{ meters}$$

$$\text{Pressure Drop } (\Delta P) = h_f \times \rho\times g = (8.5132+4.2289+2.5556)\times 998.017\times 9.81$$

$$\text{Pressure Drop } (\Delta P) = 149619.7892 \text{ Pascal}$$

#### 2) Head loss due to friction by ISHARE Standard [5]

$$(h_f) = 0.024472165 \times \frac{1.569^2}{2 \times 9.81} \times \left[ \frac{(1 \times 8) + 1 + 9.1 + (12.8 \times 2) + 26 + (1.5 \times 32) + 104}{0.08} \right] = 8.5093 \text{ meters}$$

As ISHARE has not provided any details about the Y-strainer, pressure drop due to Y-strainer is calculated using equivalent length method as per details provided in Carrier System Design Manual [2].

Pressure Drop $(\Delta P) = h_f \times \rho \times g = (8.5093 + 4.2289 + 2.5556) \times 998.017 \times 9.81$

Pressure Drop $(\Delta P) = 149734.8843$ Pascal

*B. William B. Hooper 2K Method*

This method requires two constant which correlates Reynolds number and size of fitting with pressure drop. Pressure drop calculations by 2k method are carried out using equations given below. Where Re is Reynolds number, D is diameter in inches and $K_f$ is loss coefficient [8].

$$K_f = \frac{K_1}{\text{Re}} + K_\infty \left( 1 + \frac{1}{D} \right) \qquad (2)$$

$$h_f = k_f \times \frac{V^2}{2g} \qquad (3)$$

TABLE IV
$K_1$ and $K_\infty$ Values by William B. Hooper [8]

| Fittings | BFV | MBFV | NRV | 3WBV | Elbow |
|---|---|---|---|---|---|
| $K_1$ | 800 | 800 | 1500 | 1500 | 800 |
| $K_\infty$ | 0.25 | 0.25 | 1.5 | 4 | 0.25 |

Loss coefficient ($K_f$) for BFV = $(K_f) = \frac{800}{123663.1303} + 0.25\left(1 + \frac{1}{3.1496}\right) = 0.3358$

Values of loss co-efficient for all other pipe fittings is calculated similarly by using equation (3) and table IV and represented in table V. As William Hooper [8] has not provided any details about the pressure drop due to Y-strainer, therefore pressure drop due to Y-strainer is calculated using equivalent length method as per details provided in Carrier system design manual [2]. Pressure drop due to straight pipe is calculated using equation (1).

TABLE V
Loss Co-efficient for Pipe Fittings by 2K Method

| Fittings | BFV | MBFV | NRV | 3WBV | Elbow |
|---|---|---|---|---|---|
| Loss co-efficient ($K_f$) | 0.3358 | 0.3358 | 1.9884 | 5.28213 | 0.26997 |

Head loss due to fittings $(h_f) = [(0.3358 \times 8) + 0.3358 + 1.9884 + 5.28213 + (0.26997 \times 32)] \times \frac{1.569^2}{2 \times 9.81}$

$= 2.3754$ meters

Head loss in straight pipe and Y-strainer $(h_f) = 0.024472165 \times \frac{1.569^2}{2 \times 9.81} \times \left[ \frac{(12.8 \times 2) + 104}{0.08} \right] = 4.9743$ meters

Pressure Drop $(\Delta P) = h_f \times \rho \times g = [2.3754 + 4.2289 + 2.5556 + 4.9743] \times 998.017 \times 9.81$

Pressure Drop $(\Delta P) = 138381.5462$ Pascal

*C. Darby 3K Method*

Pressure drop calculations by 3k method are carried out using equations given below [3] [4].

$$K_f = \frac{K_1}{\text{Re}} + K_i \left( 1 + \frac{K_d}{D} \right) \qquad (4)$$

TABLE VI
$K_1$, $K_\infty$ and $K_D$ Values by Darby [3] [4]

| Fittings | BFV | MBFV | NRV | 3WBV | Elbow |
|---|---|---|---|---|---|
| $K_1$ | 300 | 300 | 1500 | 1500 | 800 |
| $K_\infty$ | 0.037 | 0.037 | 0.46 | 1.7 | 0.091 |
| $K_d$ | 3.9 | 3.9 | 4.0 | 3.6 | 4.0 |

Loss coefficient for BFV = $(K_f) = \dfrac{300}{123663.1303} + 0.037\left(1 + \dfrac{3.9}{3.1496}\right)$ = 0.0852

Values of loss co-efficient for all other pipe fittings is calculated similarly by using equation (4) and table VI and represented in table VII. As Ron Darby [3][4] has not provided any details about the pressure due to Y-strainer, therefore pressure drop due to Y-strainer is calculated using equivalent length method as per details provided in carrier system design manual [2].

TABLE VII
Loss Co-efficient ($K_F$) for Pipe Fittings by 3K Method

| Fittings | BFV | MBFV | NRV | 3WBV | Elbow |
|---|---|---|---|---|---|
| Loss co-efficient ($K_f$) | 0.0852 | 0.0852 | 0.96632 | 3.65523 | 0.21304 |

Head loss due to fittings $(h_f) = [(0.0852 \times 8) + 0.0852 + 0.96632 + 3.65523 + (0.21304 \times 32)] \times \dfrac{1.569^2}{2 \times 9.81}$

= 1.5315 meters

Pressure Drop $(\Delta P) = h_f \times \rho \times g$ = $[1.5315 + 4.2289 + 2.5556 + 4.9743] \times 998.017 \times 9.81$

Pressure Drop $(\Delta P) = 130119.3037$ Pascal

TABLE VIII
Results of Analytical Methods

| Method | Darby 3K Method | William B. Hooper 2K Method | ISHARE Standard | Carrier System Design Manual Standard |
|---|---|---|---|---|
| **Pressure Drop** | 130119.3037 Pa | 138381.5462 Pa | 149734.8843 Pa | 149619.7892 Pa |

## III. PRESSURE DROP PREDICTION BY CFD ANALYSIS

For this study, three dimensional model of chilled water piping system is created using design modeler of Ansys-13. This geometry is then imported in to a meshing module. In which sweep meshing method is used along with face inflation to capture correct wall boundary condition. Details of mesh created are shown in table IX. Whereas fig. 2 shows the mesh generated for chilled water pipe.

TABLE IX
Meshing Details

| Type | Method | Element Size | Number of Elements | Number of Nodes | Aspect Ratio | Max. Skewness | Orthogonal Quality |
|---|---|---|---|---|---|---|---|
| Cell Mesh | Sweep Meshing | Minimum – 3.5 mm<br>Maximum – 8 mm<br>Max. Face Size – 4.5 mm | 7240108 | 7627530 | Max 16.43 | 0.6416 | Mini.- 0.726 |

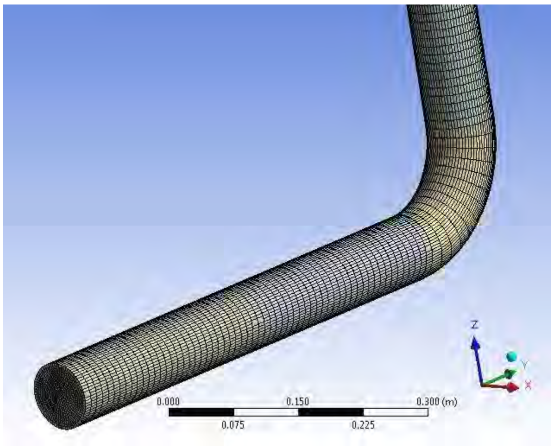


Fig. 2. Meshing For Chilled Water Pipe

Velocity inlet is used as an inlet boundary condition. Whereas usual no slip and adiabatic condition is assumed on wall surface. The pressure outlet is used as outlet boundary condition as shown in table IX. K-epsilon-realizable turbulence model is used with standard wall function for near wall treatment. For solution SIMPLE pressure-velocity coupler with least squares cell based discretization scheme is used. Tolerance of $10^{-4}$ is used for convergence criteria.

TABLE X
Boundary Conditions

| Boundary | Type | Input |
|---|---|---|
| Inlet | Velocity Inlet | 1.56892 m/sec. |
| Chiller coil pressure drop | Interface (Fan) | 25000 Pascal |
| AHU coil pressure drop | Interface (Fan) | 41368.544 Pascal |
| Pipe surface | Wall | No-slip, stationary and adiabatic wall |
| Outlet | Pressure outlet | - |

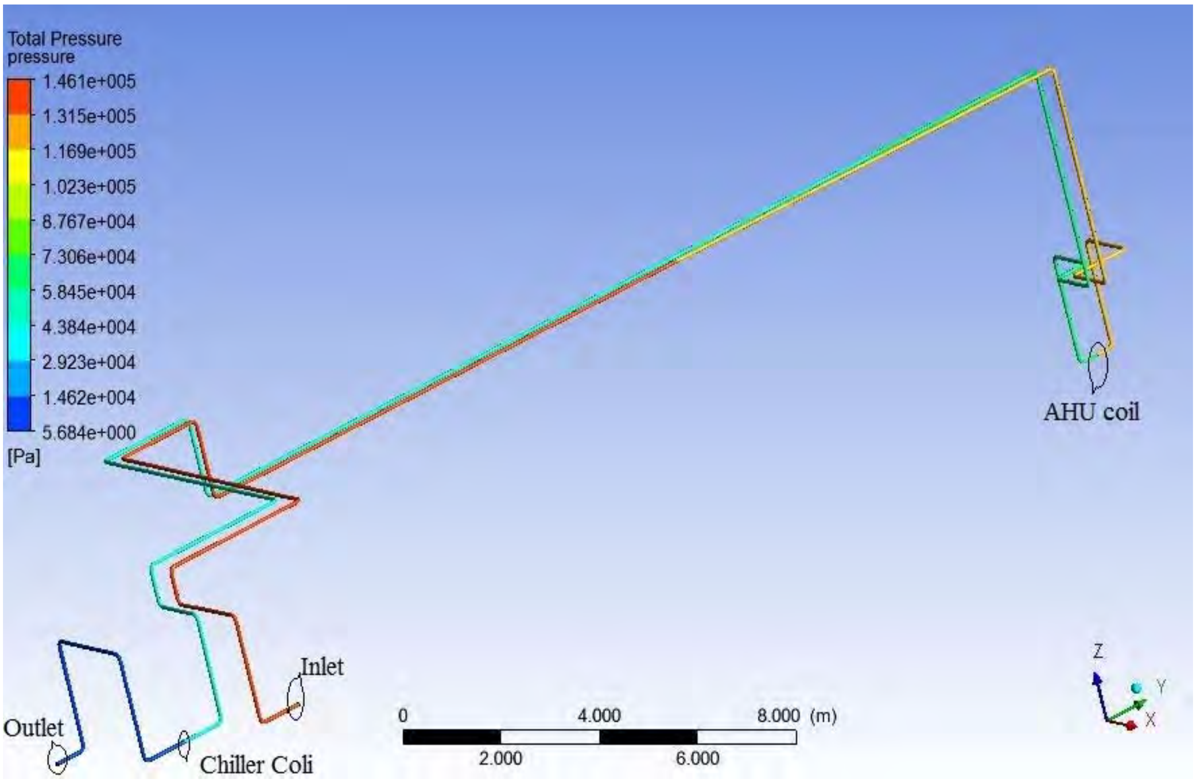


Fig. 3. Pressure contour of chilled water piping system

After Appling all the boundary conditions as shown in table IX, it is observed that the CFD analysis shows the pressure drop of 141008.5124 Pascals.

TABLE XI
Result of CFD Analysis

| Inlet Pressure | Outlet Pressure | Pressure Drop (ΔP) |
|---|---|---|
| 142254.67 Pascal | 1246.1576 Pascal | 141008.5124 Pascal |

## IV. RESULT AND CONCLUSION

Fig. 4 shows the comparison of pressure drop in chilled water piping system calculated by analytical methods and CFD analysis. Relative errors of 3K, 2K, and equivalent length method of ISHARE and carrier system design manual is calculated with respect to CFD solution and plotted in fig. 4. Whereas fig. 5 shows the variation in pressure drop calculated by analytical methods with respect to CFD analysis. It is observed that variations in pressure drop are in the acceptable range of 1.85% to 7.75% of relative error and hence CFD analysis can be used for pressure drop prediction in chilled water piping system.

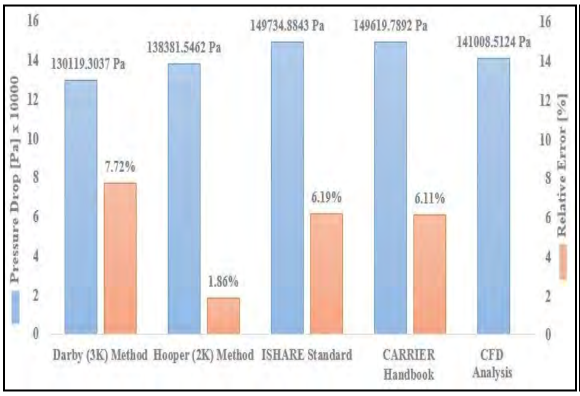


Fig. 4. Pressure Drop and Relative Error of different methods of pressure drop prediction

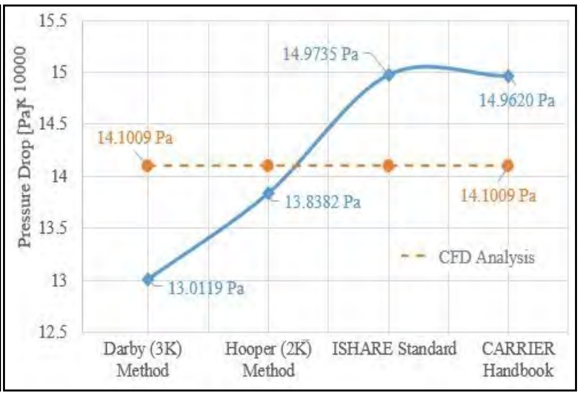


Fig. 5. Variations in pressure drop calculated by analytical methods with respect to CFD analysis

Pressure drop calculated by ISHARE and Carrier shows similar results but higher pressure drop value with relative error of 6.19% and 6.11% respectively. Whereas 3K method under predicts pressure drop value as compared to CFD results with relative error of 7.72%. However 2K method shows optimum results of pressure drop prediction with 1.86% relative error.

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