

ASDC For Windows: Air Stripper Design and Costing User Manual

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Preface

Development of the original ASDC program in 1990-1991 was sponsored by the Headquarters Air Force Civil Engineering Support Agency (HQ AFCESA), Tyndall AFB, Florida, under contract no. 8635-90-C-0099 to Carnegie Mellon University. David Dzombak was the Principal Investigator for the project. Captain Edward Marchand of HQ AFCESA served as the Project Officer.

Several commercial products related to the air stripping process are mentioned in this report and in the ASDC computer program. No endorsement or rejection of any product for the U.S. Air Force or other use should be inferred.

After the initial release of the ASDC program and user manual in 1991, several subsequent updates to the program and manual were made, with the last of those in October 1995. The program and manual were distributed at cost initially and eventually for free download when that service became widely available.

The original ASDC program was developed for use with a DOS operating system. Continued use of the program was possible even after the development of the Windows operating system, via use of with DOS emulator tools. With the increasingly limited availability of DOS emulator tools, and the tremendous advancements in the capabilities of the Windows operating system, it became clear that for the continued existence of the program modification for use in the Windows operating system was needed.

Development of ASDC for Windows began in 2012. Muhammad Sherif, then a CEE master's student at Carnegie Mellon, volunteered to lead the task of transferring the program to Windows, which essentially required complete re-programming. In 2013, Nimit Shah, also then a CEE master's student at Carnegie Mellon, joined the effort to help with testing the program and guiding its development. Vishal Vaidyanathan, another CEE master's student, also joined the effort in 2019 to assist with testing of the program and with implementing revisions to the user manual. The effort was conducted as a part-time activity for Muhammad, Nimit, and David Dzombak, for longer than any of us envisioned at the beginning! The persistence of Muhammad and Nimit with the project on a volunteer basis long after they each completed their studies at Carnegie Mellon is a testament to their professionalism and is much appreciated by David Dzombak.

This manual describes the design procedures, data, and algorithms incorporated in the program. It also provides a guide to use of ASDC for Windows. The manual contains much of the information in the original ASDC User Manual but provides updates where appropriate. Sections I-III and the appendices are largely reproduced from U.S. Air Force Report ESL-TR-91-40 (Carnegie Mellon CE Report No. 92-204), “ASDC: A microcomputer-based program for air stripper design and costing” David A. Dzombak, Hung-Jung Fang and Sujoy B. Roy, December 1991.

Availability of ASDC Software and Conditions of Use

The ASDC for Windows program is available for open access non-commercial research use. Carnegie Mellon University allows free use of the ASDC software in its “as is” condition.

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1 Introduction

ASDC for Windows is an interactive program for air stripper design and cost estimation and optimization. For a specified water treatment scenario, the Air Stripper Design and Costing (ASDC) program can generate many alternative designs simultaneously and estimate approximate capital and operating costs associated with each design. Various plots of costs versus design parameter values can be then displayed on-screen for rapid assessment of optimal design with respect to cost.

Packed tower, countercurrent air stripping has been long used in chemical process industries and this technology is employed for removal of volatile organic compounds (VOCs) from water supplies, wastewaters, contaminated groundwaters and leachate from waste disposal sites. The packed tower air-stripping process is illustrated schematically in Figure 1. Water contaminated with VOCs is pumped to the top of the column and evenly distributed over the cross-sectional area of the column which is filled with a porous packing material. Air is introduced at the bottom of the column and flows upward, counter to the downward water flow. The packing material serves to maximize the water surface area in the column, and exchange of VOCs from water to air occurs at the air/water interfaces the column. Water with reduced VOC concentrations exits at the bottom of the column and air containing VOCs is discharged at the top column. Treatment of the off gas is sometimes required. Several studies have shown that air stripping, even with off-gas treatment, can be a cost-effective method for removal of VOCs from water particularly when compared with treatment by adsorption on granular activated carbon (References 1-4).

Design of an air-stripping unit is performed using a well-developed mathematical model of the process which is based on principles of mass transfer. Because the number of variables exceeds the number of constraining equations, however, a variety of air stripper designs can be employed to achieve a desired removal for a compound. An air stripper is typically designed by assuming values for the extra variables (usually the stripping factor, which reflects the air-water ratio, and the gas pressure drop across the column), generating designs for different assumed values, estimating costs for the various designs, and then selecting the optimum design by considering process requirements and costs. Air stripper design calculations are relatively straightforward but numerous. As the design procedure is iterative, design via manual calculation can be tedious and subject to mathematical errors. Because of this, and because cost data are difficult to assemble,

design of air-stripping units in the past has often involved generation of only a few feasible designs and use of engineering judgement to select the final configuration. As a result, designs for many existing air-stripping units in use for water treatment are not optimal with respect to cost (e.g., Reference 5).

In the following sections of the report, the design and cost estimation components of the ASDC for Windows program are described in detail and a guide to operation of the program is presented. The program operation guide contains descriptions of the function and invocation of menus, and the structure, and format of input and output. Example applications exercising the major options in ASDC for Windows are also presented and include reproductions of the corresponding input and output screens.

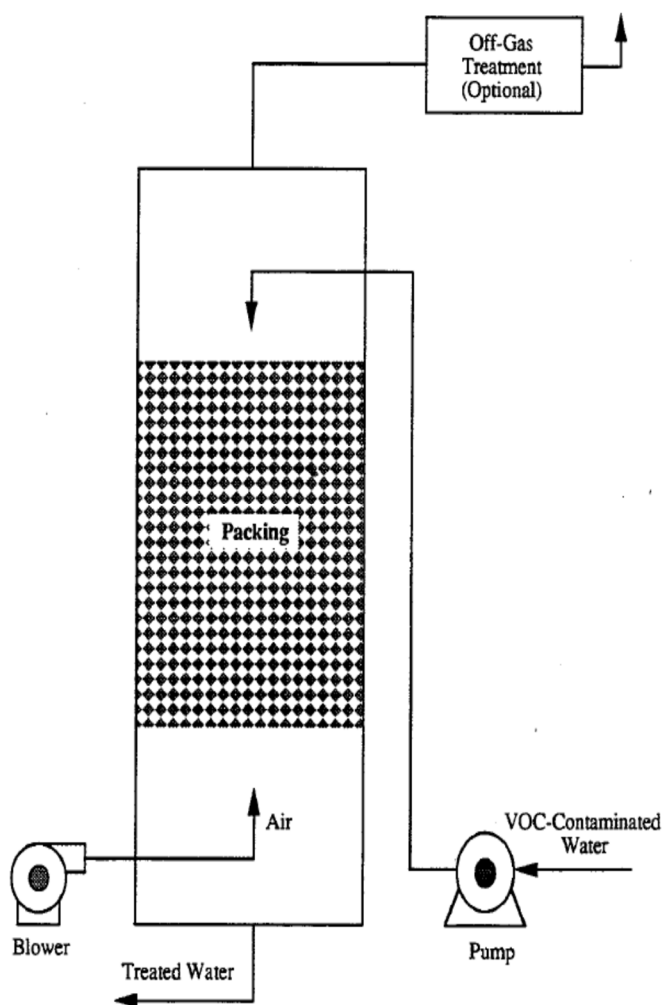


Figure 1-1. Schematic of an Air-Stripping Unit

2 Air Stripper Design

The theory of countercurrent packed-tower operation for gas/liquid absorption and stripping applications is well developed in the chemical engineering mass transfer literature (e.g., References 10 and 11). Several excellent papers have been published which describe the application of this theory to the design of air-stripping units for water and wastewater treatment (References 12-14). In addition, the USEPA sponsored development of a process design manual (Reference 15) for air and steam stripping which summarizes the design methods. Also, air stripper design is described in several U.S. Air Force reports (References 16,17). The air stripper design procedure described in the cited articles is employed in the ASDC program. A summary of the design procedure is provided below, followed by detailed explanations of how certain aspects of the design procedure are implemented in ASDC.

2.1 Overview of Design Methodology

In designing an air-stripping unit, the goal is to determine the packed-tower configuration (diameter and height of packing material), air loading rate (moles/area-time), and water loading rate (moles/area-time) that will enable reduction of a given influent concentration C_i of a volatile contaminant to a desired effluent concentration C_e at minimum cost for a specific inflow rate Q and set of environmental conditions (air and water temperatures, atmospheric pressure). The designer must determine values or ranges of values for C_i , C_e , Q , the air and water temperatures (T_{air} , T_{water}), and the atmospheric pressure (P_{atm}), and then select some candidate packing materials. Air stripper design theory (References 10-14) can then be employed to identify several alternative designs.

The Henry's Law constant, K_H in atm-m³/mol or H in dimensionless form, is a compound property that provides an indication of the relative volatility of the compound. It expresses the ratio of a compound's abundance in the gas phase to that in the aqueous phase at equilibrium and is an important parameter in air stripper design. If $K_H < 10^{-7}$ atm-m³/mol, the compound is considered to exhibit low volatility, while at K_H values greater than 10^{-7} but less than 10^{-5} atm-m³/mol, the compound will volatilize moderately from water. Compounds with K_H values in the range $10^{-5} < K_H < 10^{-3}$ atm-m³/mol are moderately to highly volatile and most easily removed by air stripping. Values of K_H exceeding 10^{-3} atm-m³/mol indicate high volatility of a compound.

The methodology of air stripper design is based on four basic equations derived from mass transfer theory:

$$Z = \text{Packing Height (m)} = HTU \times NTU \quad (1)$$

$$HTU = \text{Height of Transfer Unit (m)} = \frac{L_m}{K_L a \rho_L} \quad (2)$$

$$NTU = \text{Number of Transfer Unit} = \frac{R}{R-1} \times \ln \left(\frac{(C_e/C_i)(R-1) + 1}{R} \right) \quad (3)$$

$$R = \text{Stripping Factor} = \left(\frac{G_m \rho_L}{L_m \rho_G} \right) \times H \quad (4)$$

where K_L is the overall liquid phase mass transfer coefficient (m/s), a is the specific interfacial area for the packing (m^2/m^3), ρ_L is the density of water (kg/m^3), ρ_G is the density of air (kg/m^3), R is the stripping factor (dimensionless), H is the Henry's Law constant for the VOC of interest (dimensionless), C_i and C_e are the influent and effluent concentrations, and L_m and G_m are the liquid and gas mass loading rates ($\text{kg}/\text{m}^2\text{-s}$). Thus, the design is constrained by four equations and there are six unknown variables: Z , HTU , NTU , R , G_m , and L_m . Substitution of Equations (2) and (3) in Equation (1) yields:

$$Z = \left(\frac{L}{K_L a \rho_L} \right) \left(\frac{R}{R-1} \right) \ln \left(\frac{(C_e/C_i)(R-1) + 1}{R} \right) \quad (5)$$

Equation (5) can be used in design calculations to estimate the height of packing material needed to achieve a given treatment objective, but values for R (and hence the air: water ratio, $G_m \rho_L / L_m \rho_G$) and G_m (needed to obtain L_m) must be fixed arbitrarily for this calculation. The overall liquid phase mass transfer, $K_L a$, for the contaminant is obtained from available data or by experiment. As G_m , the gas loading rate is related directly to the pressure drop, ΔP , the design variables are usually considered to be R and ΔP . Thus, the design engineer must assume a desirable pressure drop value for gas flow across a packed column corresponding to a particular value for the gas loading rate. Choosing a particular set of values for R and ΔP fixes the value of G_m and all other variables.

The general design procedure for an air stripper for one set of R and ΔP values is as follows:

1. Identify design contaminant of interest and choose a packing material.
2. Specify system design parameters (influent concentrations; required effluent concentrations; water inflow rate; water temperature; atmospheric pressure; $K_L a$, if available)
3. Choose values for R and ΔP
4. Calculate G_m/L_m using Equation (4)
5. Determine G_m for specified ΔP value using Eckert relationships
6. Calculate L_m
7. Estimate $K_L a$ using Onda model (Reference 22) if pilot data are not available
8. Calculate HTU and NTU using Equations (2) and (3)
9. Calculate Z using Equation (1)
10. Calculate the tower diameter based on known water inflow rate, Q and L_m

Thus, with the specification of R and ΔP the design is fixed. The design problem is to find the set of R and ΔP values that corresponds to minimum total cost for the unit and that is consistent with other non-cost constraints or goals. Key components of the design procedure, including use of the Eckert relationships and the Onda model, are described in the following subsections.

2.2 Algorithm for Selection of Design Contaminant

If a set of contaminants are specified in the scenario, design calculations are performed for the compound having the highest NTU (number of transfer units) and R (stripping factor) greater than 1. Preliminary NTU estimates are made by applying the Onda model, with an assumed air:water ratio of 30, to each of the contaminant specified by the user in the scenario. The NTU and R criteria are then applied to these results. Note that if the calculated air:water ratio is substantially different from 30, the ranking used to select the component as the basis of air stripper design may not be correct. In ASDC for Windows, the user has the option to specify the compound for which the designs will be determined, i.e., the user has the option to over-ride the design contaminant selected by the program.

2.3 Estimation of Mass Transfer Coefficient

The two-phase resistance or two-film theory is generally accepted and widely used for description of mass transfer in gas-liquid exchange processes (References 11, 18). In the two-phase resistance

theory, a solute is considered to be transported from the bulk of one phase to the interface, and then from the interface to the bulk of the second phase. A stagnant film of finite thickness exists on each side of the interface, and the solute molecules must diffuse through these films before passing from the liquid phase to the gas phase, as illustrated in Figure 2. The two-phase resistance theory assumes that the only resistances to interphase exchange are the diffusional resistances in the stagnant films and that solute transfer across the interface itself is governed by Henry's Law of vapor-liquid equilibrium. The overall resistance to mass transfer is the sum of two separate resistances, a liquid-phase and a gas phase resistance:

$$R_T = R_L + R_G \quad (6)$$

In accordance with two-phase resistance theory, these resistances R_L and R_G are defined as the reciprocals of their respective phase transfer rate constants. With the assumption that phase equilibrium exists at the interface, the following equation is obtained:

$$\frac{1}{K_L a} = \frac{1}{k_L a} + \frac{1}{H(k_G a)} \quad (7)$$

where K_L is the overall liquid-phase mass transfer coefficient, k_L is the individual liquid phase coefficient, k_G is the individual gas phase coefficient, and a is the effective interfacial area per unit volume of liquid. From the above equation, the significance of each phase in controlling the rate of gas-liquid mass transfer can be evaluated. For highly volatile contaminants which have larger H values, the gas-phase resistance is negligible and liquid phase control of mass transfer exists. For compounds of moderate to low volatility, both phase resistances must be considered for predicting and interpreting mass transfer rates.

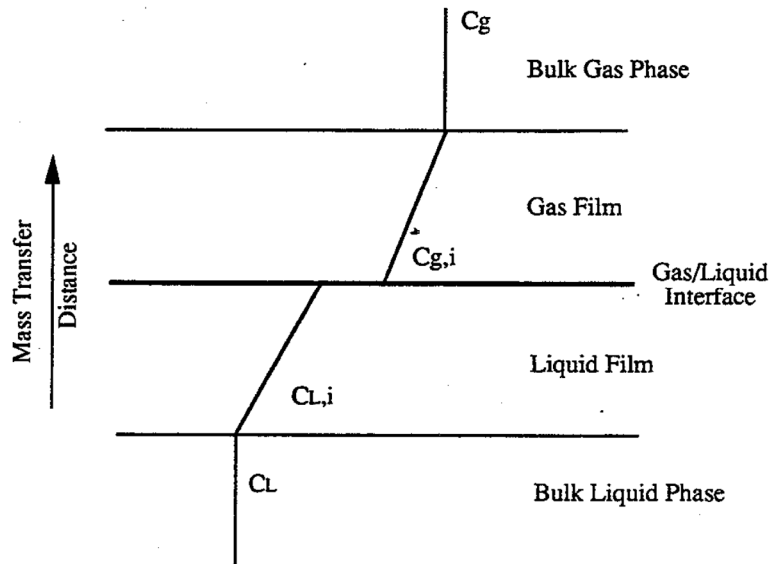


Figure 2-1. Two-Phase Resistance Model for Chemical Exchange at the Gas/Liquid Interface

Overall liquid-phase mass transfer coefficients for specific applications can be determined experimentally in pilot tests (Reference 13) or can be estimated using one of several available models. Three models for prediction of mass transfer coefficients in countercurrent packed columns are those by Sherwood-Holloway, Shulman, and Onda. These models are reviewed by Roberts et al. (Reference 19).

The Sherwood-Holloway model (Reference 20) was developed from a study of the desorption of hydrogen, carbon dioxide, and oxygen from water into a countercurrent air flow in packed column tests involving several sizes of Raschig ring and Berl saddle packing materials. As the gaseous solutes tested by Sherwood and Holloway have sufficiently large Henry's Law constants that liquid-phase resistance controls, the overall mass transfer rate predicted with the Sherwood-Holloway correlation is governed by liquid resistance only. In addition, the correlation does not consider the effective interfacial area explicitly. This estimation method is difficult to apply to a new type of packing material.

The Shulman and Onda models (References 21, 22) estimate both gas and liquid phase resistance values and estimation of interfacial contact area is also included. These models are, therefore, valid for a wider range of contaminants, regardless of volatility. The main item of concern for the Shulman model lies in the correlation used for prediction of interfacial area. It is not general and applies only to specific situations. This is a critical deficiency since the original work involved only a limited number of packing types. Therefore, without further information on the appropriate

values of interfacial area for use with modern packings, this model is extremely limited in terms of potential applications.

The correlation developed by Onda et al. (Reference 22) entails separate estimation of the individual phase resistance values, k_L and k_g and the interfacial area, a . The specific interfacial area is taken to be the specific wetted packing area, a_w (Reference 19), which is estimated as a function of the liquid flow rate, packing properties, and liquid properties according to the following equation:

$$\frac{a_w}{a_t} = 1 - \exp \left[-1.45 \times \left(\frac{\sigma_c}{\sigma_L} \right)^{0.75} \times \left[\frac{L_m}{a_t \mu_L} \right]^{0.1} \times \left[\frac{L_m^2 a_t}{\rho_L^2 g} \right]^{-0.05} \times \left[\frac{L_m^2}{\rho_L \sigma_L a_t} \right]^{0.2} \right] \quad (8)$$

where

a_t = total specific surface area of packing

σ_c = critical surface tension of packing material

σ_L = surface tension of the liquid

L_m = liquid mass loading rate

μ_L = liquid viscosity

ρ_L = liquid density

g = gravitational constant (9.81 m/s²)

The last three factors within the argument of the exponential in Equation (8) are the Reynolds, Froude, and Weber numbers, all dimensionless. According to the original developers, Equation (8) is accurate within ± 20 percent. For a given packing material, liquid, and temperature, the specific interfacial area increases with increasing liquid loading rate and asymptotically approaches a_t as L_m becomes very large.

In the Onda model, the correlation for the liquid-phase coefficient, k_L was determined from interpretation of a large data base (including the data of Sherwood and Holloway), encompassing packed tower tests with rings, spheres, rods, and saddles from 4 to 50 mm size, covering the liquid flow range $0.8 < L_m < 43 \text{ kg.m}^{-2}\text{s}^{-1}$. The correlation is given in dimensionless form as:

$$k_L \left(\frac{\rho_L}{\mu_L g} \right)^{\frac{1}{3}} = 0.0051 \times \left(\frac{L_m}{a_w \mu_L} \right)^{\frac{2}{3}} \times \left(\frac{\mu_L}{\rho_L D_L} \right)^{-0.5} \times (a_t d_p)^{0.4} \quad (9)$$

where d_p is the nominal packing size and D_L is diffusivity of the contaminant in the liquid. The accuracy of the estimate of k_L is reported to be ± 20 percent.

For the gas-phase resistance, Onda et al. correlated mass- transfer data for absorption and stripping in the gas flow range $0.014 < G_m < 1.7 \text{ kg.m}^{-2}.\text{s}^{-1}$ and various packing shapes in the size range 4 to 50 mm. They obtained the following relationship for k_G in dimensionless form:

$$\frac{k_G}{a_t D_G} = 5.23 \times \left(\frac{G_m}{a_t \mu_G} \right)^{0.7} \times \left(\frac{\mu_G}{\rho_G D_G} \right)^{\frac{1}{3}} \times (a_t d_p)^{-2} \quad (10)$$

where D_G is the diffusivity of the contaminant in the gas phase and G_m is the air mass loading rate. The value of the constant in Equation (10) is changed for small packing ($d_p < 15 \text{ mm}$) from 5.23 to 2.0. The overall accuracy for the k_G correlation was placed at ± 20 percent in the original work.

The ASDC program incorporates the Onda model for estimation of the overall mass transfer factor, $K_L a$, as well as an option to specify a safety factor for the estimated value. Gosset et al. (Reference 16), Robens et al. (Reference 19), and Hand et al. (Reference 14) have validated the Onda correlation in pilot and field studies. These and other studies reported in the environmental engineering literature have found the Onda correlation to be the most accurate of the three available models for estimation of $K_L a$ in packed-tower stripping of VOCs. Implementation of the Onda model requires property data for the water (μ_L , ρ_L , σ_L), the air (μ_G , ρ_G), the packing material (a_t , d_p) and the contaminant of interest (H , D_L , D_G), as well as the water and air mass loading rates (L_m , G_m).

In the ASDC for Windows program, property data for the contaminant, the packing material, water and air are accessed from data bases while L_m and G_m are calculated. Property data for the water and air are adjusted for the appropriate temperature as discussed later in the report. Contaminant diffusion properties, namely D_L and D_e , are estimated using methods recommended by Lyman et al. (Reference 23, Chapter 17). For D_L the estimation equation of Hayduk and Laudi (Reference 24) is employed:

$$D_L = \frac{13.26 \times 10^{-5}}{\mu_L^{1.14} V_B^{0.589}} \quad (11)$$

where μ_L is the water viscosity (centipoise) at the temperature of interest, V_B is the molar volume (cm^3/mol) of the contaminant, and D_L has units of cm^2/sec . The estimation method of Wilke and Lee (Reference 23, Chapter 17) is used for D_G :

$$D_G = \frac{B'T^{1.5}\sqrt{M_r}}{P\sigma_{AB}^2\Omega} \quad (12)$$

where T is the temperature in K, P is the pressure in atm, B' , Ω , and σ_{AB} are parameters defined as:

$$B' = 0.00217 - 0.00050 \sqrt{\frac{1}{M_a} + \frac{1}{m_B}} \quad (13)$$

where M_A and M_B are the molecular weights of air and the contaminant of interest, and

$$\Omega = \frac{a}{(T^*)^b} + \frac{c}{\exp(T^* \times d)} + \frac{e}{\exp(T^* \times f)} + \frac{g}{\exp(T^* \times h)} \quad (14)$$

where $a=1.06036$, $b=0.15610$, $c=0.19300$, $d=0.47635$, $e=1.03587$, $f=1.52996$, $g=1.76474$, $h=3.89411$ and,

$$T^* = \frac{T}{\sqrt{78.6 \times 1.15T_b}} \quad (15)$$

where T_b is the boiling point of the compound in °K, and T is the temperature of interest in °K.

σ_{AB} is defined as,

$$\sigma_{AB} = \frac{3.711 + 1.18 \times (V_b)^{1/3}}{2} \quad (16)$$

where V_B is the molar volume of the compound of interest in cm³/mol.

M_r is a weighted average molecular weight, and D_G has units of cm²/sec. The parameter M_r is defined as:

$$M_r = \frac{(M_A + M_B)}{M_A M_B} \quad (17)$$

where M_A is the molecular weight of air and M_B is that of the contaminant.

2.4 Estimation of Air Loading Rate

The VOC removal efficiency of air stripping units is enhanced at higher flow rates through the packed column, but with greater air flows, larger pressure drops result and operating energy requirements increase. Pressure drop occurs in a packed tower as a result of frictional resistance of the gas to the liquid as it flows over the packing material and over the column equipment (i.e. air duct, support plate, distributor, and mist eliminator, etc.). The frictional resistance increases as the velocity of the countercurrent flowing gas increases. In air stripper design, the task is to select

as high an air loading rate as possible for a particular packing and a specified maximum allowable gas pressure drop across the column.

Pressure drops associated with different gas loading rates in countercurrent flow packed towers have been measured for various types of random packing. These data have been summarized in “generalized pressure drop curves” relating to G and ΔP which enable estimation of acceptable gas loading rates for a wide range of conditions. Sherwood et al. (Reference 20) performed experiments with a Raschig ring random packing and a variety of gases (air, hydrogen, carbon dioxide) and liquids (water, aqueous glycerol, methanol, aqueous butyric acid). They published a correlation to predict “flooding” (pressure drop so high that gas cannot flow through the tower) as a function of column dimensions and physical characteristics of the gas and the liquid. However, Lobo et al. (Reference 26) observed that the Sherwood packed-bed geometry factor, a/E^3 (the area of the packing in square feet per cubic foot divided by the cube of the fractional void space) was not useful for accurate prediction of gas flow capacity for ΔP values at non-flooding conditions. Later, Leva (Reference 27) introduced the parameter of constant pressure drop and a further correction for the ratio of the density of water to the density of the liquid in the packed bed, Eckert (Reference 28) used a modification of the capacity factor of Lobo and called it the “packing factor”, F . Eckert’s packing factor was established by averaging the observed capacities of the bed under the conditions outlined by Lobo et al., with the exception that they were measured at pressure drops of 0.5, 1.0 and 1.5 inch H₂O per foot of packed height rather than at the flooding point. The generalized pressure drop correlation of Eckert is recommended by Perry’s Chemical Engineers’ Handbook (Reference 29) as the best tool for estimating acceptable gas loading rates. A set of generalized pressure drop curves (**Error! Reference source not found.**), obtained from the Norton Company (Akron, Ohio), are used for estimation of G in the ASDC program.

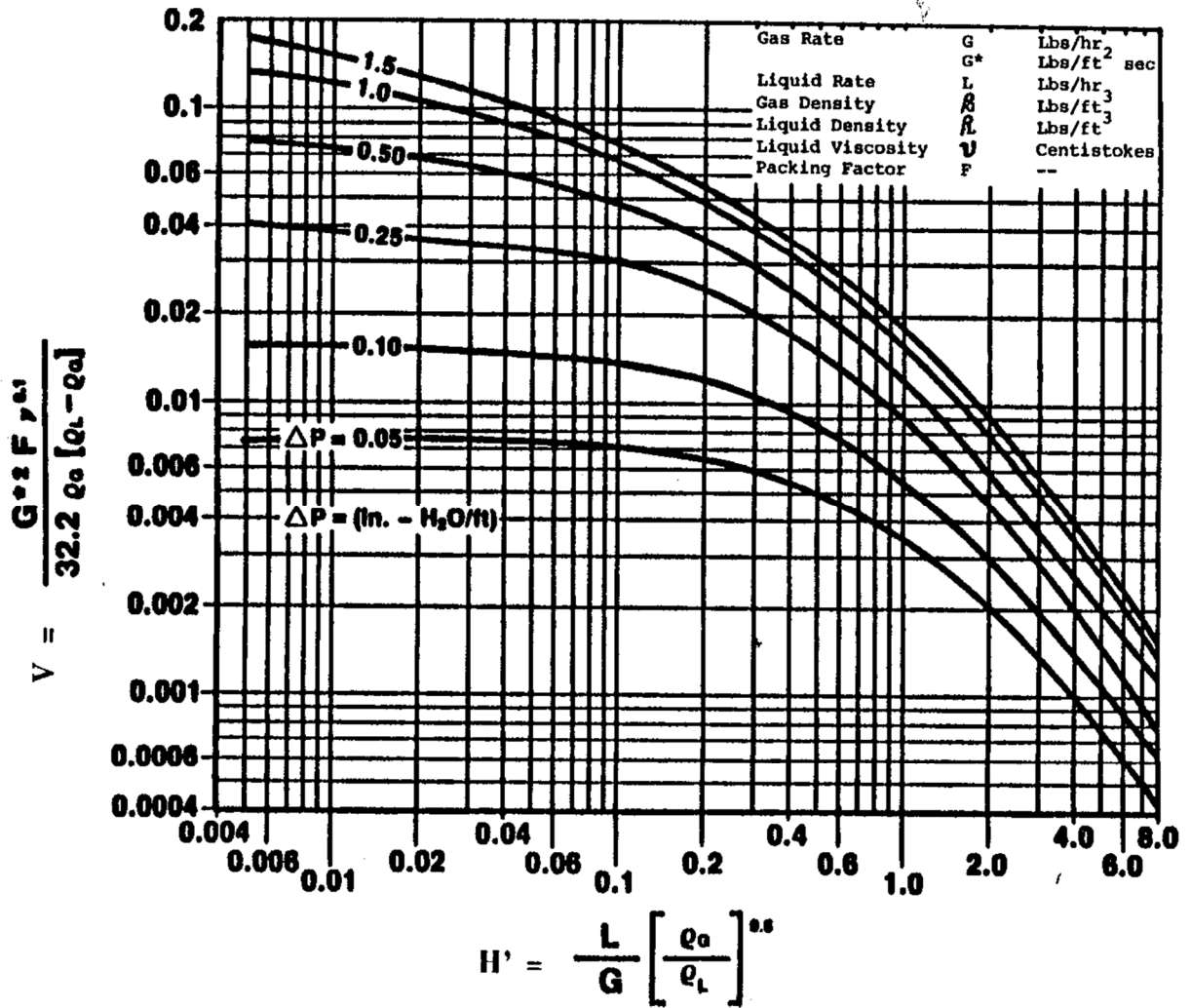


Figure 2-2. Generalized Pressure Drop Curves (Norton Company, 1988)

On the Eckert correlation plot of **Error! Reference source not found.**, the abscissa is known as the flow parameter

$$H' = \frac{L}{G} \left(\frac{\rho_G}{\rho_L} \right)^{0.5} \quad (18)$$

and the ordinate is the capacity parameter:

$$V = \frac{G^2 F \mu_L^{0.1}}{g \rho_G (\rho_L - \rho_G)} \quad (19)$$

where L and G refer to the liquid and gas loading rates in lbs/hr, g is the gravitational constant (32.2 ft/s²), ρ_G is the gas density (lb/ft³), ρ_L is the liquid density (lb/ft³), μ_L is the liquid viscosity

(Centipoise), and F is the packing factor (ft^{-1}). To facilitate use of Eckert correlation curves, the linearization method developed by Prahl (Reference 30) and employed by Boadway (Reference 31) was adopted. The Prahl method provides a means to represent the nonlinear Eckert correlation curves with the simple linear equations. It was implemented in the ASDC program via the following steps:

1. Numerical values of the flow parameter H' and the capacity parameter V were read with a digitizer from the generalized pressure drop curves for different pressure drops.
2. Values for $\Delta P/V$ were calculated for values of H' .
3. $\Delta P/V$ was plotted versus ΔP for different values of H' . Straight lines (with slope = m and y-intercept = n) were fitted to these points as shown in Figure 2-3a.
4. The lines for the individual H' values were expressed by equations of the type:

$$V = \frac{G^2 F \mu_L^{0.1}}{g \rho_G (\rho_L - \rho_G)} \quad (20)$$

Values of m and n for different H' were taken from Figure 2-3a.

5. The m and n values for the individual H' lines were plotted versus H' , and a straight line (with slope = p and y-intercept = q) was fitted to the points. The same was done for the n values (slope = r and y-intercept = s). These lines, shown in Figure 2-3b, may be expressed as:

$$m = pH' + q \quad (21)$$

$$n = rH' + s \quad (22)$$

6. Rearrangement of Equation 16 gives the final equations implemented in the ASDC program

$$\Delta P = \frac{V_n}{1 - V_m} \quad (23)$$

$$V = \frac{\Delta P}{m\Delta P + m} \quad (24)$$

where m and n are defined as in Equations (21) and (22), In the process of applying above procedures, it was found that no single set of p , q , r and s values could be used to represent accurately the generalized pressure drop curves for the entire range of flow parameter H' . Therefore, fitting was performed for three different ranges of the flow parameter for accurate fitting of the data. The three different ranges for H' were from 0.004 to 0.2, 0.2 to 2 and 2 to 8.

The first two ranges were fitted according to the procedures described above, and two sets of p , q , r and s values were obtained. For H' less than 0.2, the best fit values were $p = 68.64$, $q = 2.21$, $r = 3.04$ and $s = 6.03$ for H' between 0.2 and 2 the best fit values were $p = 40.74$, $q = 5.63$, $r = 10.08$ and $s = 4.8$. At higher flow parameter values, i.e. H' greater than 2, the relationship between H' and V for a particular ΔP value is approximately linear on a log-log scale. Therefore, a linear regression equation was obtained to describe the generalized pressure drop curve at higher H' values:

$$\log V = -1.74 + 0.398 \log \Delta P - 1.22 \log H' \quad (25)$$

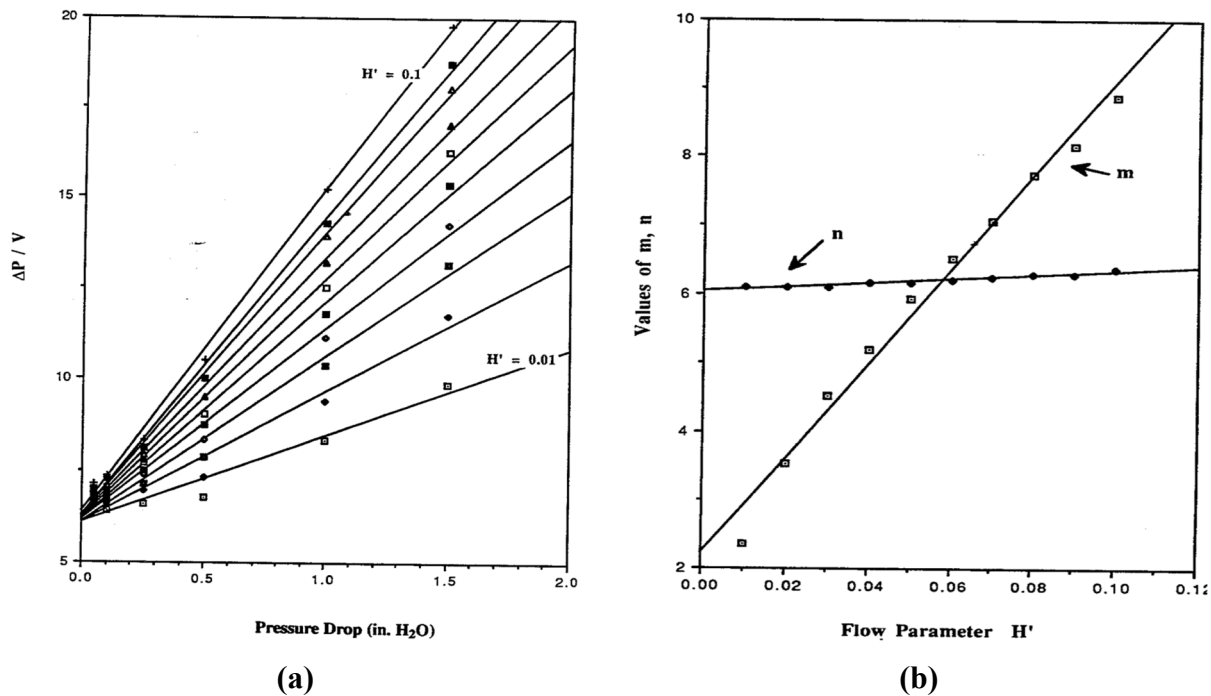


Figure 2-3. (a) $\Delta P/V$ vs ΔP (for $H' = 0.01 - 0.1$) and (b) m, n vs. Flow Parameter H' ; Prahl Linearization

Figure 2-4 shows a comparison of calculated V versus H' curves with the actual curves from the Eckert generalized pressure drop correlation. The fitting relationships used to generate the fitted curves enable prediction of V given H' for any value of ΔP in the range covered; thus, they serve as an interpolation device as well as a fitting device.

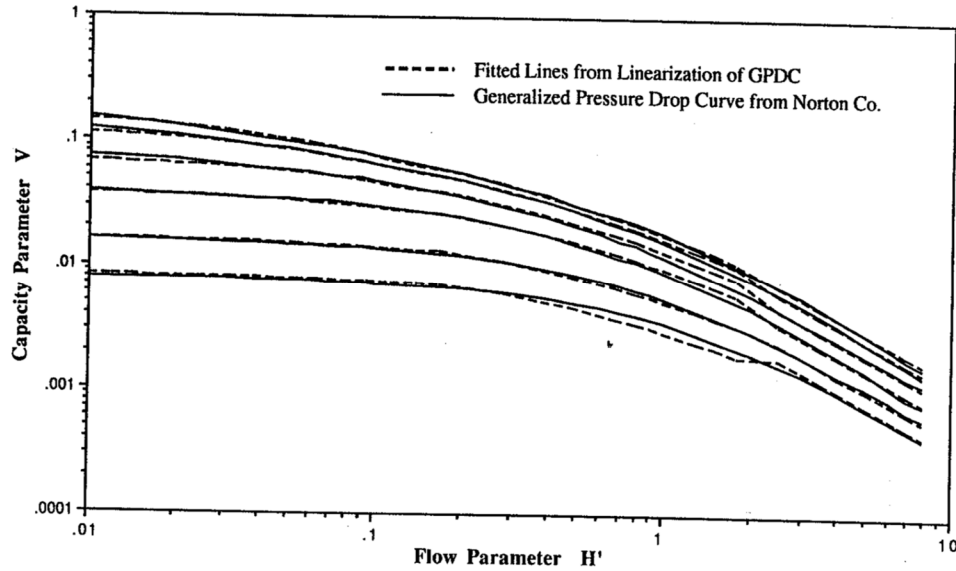


Figure 2-4. Linearization Fits of the Generalized Pressure Drop Curves

Kister et al. (Reference 32) used about 2,800 processed pressure drop data to evaluate the Eckert relationship. Overall, they found that the Eckert correlation yields good pressure drop predictions for the air/water system at atmospheric pressure throughout the entire flow parameter range. Some shortcomings related to use of the Eckert relationship were noted, however. First is the inaccuracy inherent in any graphical method. Second is the large distance between the ΔP lines, which can make graphical interpolation difficult. The fitting and interpolation algorithm for the generalized pressure drop curves that is incorporated in the ASDC program avoids these problems.

The generalized pressure drop curves are empirical and extrapolation is not reliable. Thus, in ASDC the specified pressure drop must be within the ΔP data range on the Eckert plot, i.e., from 0.05 to 1.5 inch of water/ft (41 to 1225N/m².m).

A generic flooding curve is indicated on the Eckert plot for ΔP in the range of 2 to 4 inches of water per foot of packing. However, Kister et al. (Reference 32) examined about 200 flood conditions and found that, while the flood point is independent of the flow parameter, it varies within a packing family and among packing types. Similar observations have been reported by Zenz (Reference 33) and Strigle and Rukovena (Reference 34). Kister et al. developed the following empirical equation for estimating the flood point for a packing material:

$$\Delta P_{flood} = 0.115F^{0.7} \quad (26)$$

where ΔP flood is the pressure drop at the flood point and F is the packing factor for the packing material in ft^{-1} . This equation is implemented in the ASDC program for providing the upper limit of the pressure drop that can be specified.

2.5 Temperature Dependency of Henry's Law Constant

In the overview of air stripper design methodology presented in section 2.1. it is shown that the value of the Henry's Law constant has a significant influence on the calculated design. It affects NTU directly and HTU indirectly through $K_L a$. Thus, accurate values for Henry's Law constants are critical for useful design calculations. The ASDC program includes a compound property data base which contains H values at 20°C and 25°C. Since Henry's Law constants can vary significantly with temperature, it is important to use H values for the relevant water temperature in performing design calculations. ASDC includes an algorithm to adjust H values in the data base to the water temperature of interest. The basis for this algorithm is described below.

For a compound i , the equilibrium air-to-water partition constant (the dimensionless Henry's Law constant) is given by:

$$H = \frac{P_{i,a}/RT}{C_{i,w}} \quad (27)$$

where $P_{i,a}$ is the partial pressure of compound i in the gas phase (atm) and $C_{i,w}$ is the molar concentration of the compound in water, R is the gas constant ($0.08206 \text{ L.atm.mol}^{-1} \cdot \text{K}^{-1}$), and T is the temperature in °K. For the relatively low aqueous phase concentrations of most VOCs,

$$H = H^{sat} = \frac{P_{i,L}^0/RT}{C_{i,w}^{sat}} \quad (28)$$

where $P_{i,L}^0$ is the vapor pressure over the pure organic (liquid) compound at the temperature of interest, and $C_{i,w}^{sat}$ is the aqueous phase solubility. The close correlation of H with vapor pressure and aqueous solubility enables evaluation of the temperature dependency of H . With use of the Clausius-Clapeyron equation, and consideration of temperature effects on aqueous solubility, it may be shown that

$$\ln H = -\left(\frac{\Delta H_v + \Delta H_s^e}{R}\right)\frac{1}{T} + A' \quad (29)$$

where ΔH_v is the molar heat of vaporization (cal/mol), ΔH_s^e is the excess molar heat of solution (cal/mol), R is the molar gas constant (1.9872 cal/mol-K), and A' is a constant. For most small

and/or polar compounds, ΔH_s^e is close to zero or slightly negative and is usually much smaller than ΔH_v . The influence of temperature on H is, at maximum, similar in magnitude to the influence of temperature on vapor pressure, approximately doubling for a 20°F increase. Thus, knowledge of H at a temperature (e.g., 20°C) may be used for estimation of H at another temperature by the following equations if ΔH_v is known for each compound at different temperatures.

$$\ln H(T_1) = -\frac{\Delta H_v(T_1)}{R} \frac{1}{T_1} + A' \quad (30)$$

$$\ln H(T_2) = -\frac{\Delta H_v(T_2)}{R} \frac{1}{T_2} + A' \quad (31)$$

Subtraction of Equation (30) from (31) yields:

$$\ln \frac{H(T_1)}{H(T_2)} = \frac{\Delta H_v(T_1)}{R} \frac{1}{T_1} - \frac{\Delta H_v(T_2)}{R} \frac{1}{T_2} \quad (32)$$

In the ASDC program, Equation (32) is used to estimate H at any specified temperature using H ($T_l = 20^\circ\text{C}$ or 25°C) as the reference value. All ΔH_v values required for this calculation are estimated using the method of Haggenmacher (described below) which estimates ΔH_v from vapor pressure and requires knowledge of critical pressure (P_c) critical temperature (T_c), and the Antoine constants for each compound. These data, together with H ($T = 20^\circ\text{C}$ or 25°C), have been incorporated in the compound property data base that accompanies the program.

2.5.1 Estimation of ΔH_v

The vapor pressure curve for any compound as a function of the temperature can be described by the Clapeyron Equation.

$$\frac{dP}{dT} = \frac{\Delta H_v}{T(V_G - V_L)} \quad (33)$$

where dP/dT is derivative of vapor pressure with respect to temperature, ΔH_v is the molar heat of vaporization at temperature T , V_G is the saturated molar volume of the vapor phase, and V_L is the saturated molar volume of the liquid phase. The quantity $(V_G - V_L)$ can be obtained from the compressibility equation of state:

$$V_G - V_L = \frac{RT}{P} (Z_G - Z_L) \quad (34)$$

where R is the universal gas constant and Z_G and Z_L are the compressibility factors for the vapor and the liquid phases, respectively. Substitution of Equation (34) into the Clapeyron equation and rearrangement yields:

This equation can be employed for estimating the heat of vaporization of a compound or predicting the shape of its vapor pressure curve.

$$\frac{d(\ln P)}{d\left(\frac{1}{T}\right)} = \frac{-\Delta H_v}{R(Z_G - Z_L)} \quad (35)$$

Vapor pressure versus temperature data for a compound may also be described by the Antoine relationship:

$$\log P = A - \frac{B}{t + C} \quad (36)$$

where A , B , and C are constants and t are temperature, all expressed in °C except A , which is dimensionless. The Antoine relationship is a widely used empirical tool for describing and estimating vapor pressure as a function of temperature. Antoine constants A , B , and C have been compiled for many compounds.

The Haggmacher method (Reference 23, Chapter 13) for estimating ΔH_v is derived from combination of Equation (36) with Equation (35) and the following:

$$Z_G - Z_L = \left[1 - \frac{(P/P_c)}{(T/T_c)^3} \right]^{0.5} \quad (37)$$

which expresses the compressibility difference in terms of two pressures and two temperatures, Equation (37) provides a good approximation at temperatures near or below the boiling point, T_b . ΔH_v for any temperature is computed by finding ΔH_{vb} , the heat of vaporization at the boiling point using Equation (38), and then applying Equation (39):

$$\Delta H_{vb} = \frac{2.303 B R T_b^2 \left[1 - \frac{(P/P_c)}{(T_b/T_c)^3} \right]^{0.5}}{(t_b + C)^2} \quad (38)$$

$$\Delta H_v = \Delta H_{vb} \left(\frac{1 - (T/T_c)}{1 - (T_b/T_c)} \right)^n \quad (39)$$

where T , T_b and T_c are in °K, P and P_c are in atmospheres, and B , C and t_b are in °C (t_b is the boiling point of the compound in °C; B has the same numerical values regardless of the units; C is converted from °K to °C by adding 273.15). The constant 2.303 is the natural logarithm of 10, and R is the gas constant equal to 1.9872 cal/mol.K.

The value of the parameter n in Equation (39) is given as a function of T_b/T_c (Reference 23, Chapter 13):

T_b/T_c	n
<0.57	0.30
0.57 to 0.71	$0.75(T_b/T_c) - 0.116$
>0.71	0.41

Equations (38) and (39) are employed in the ASDC program to estimate the heat of vaporization at different temperatures. To enable use of these equations, values of P_c and T_c are included in the compound property data base. In the case of compounds for which P_c , T_c and/or Antoine constants are not available, ΔH_v is estimated by use of an approximation.

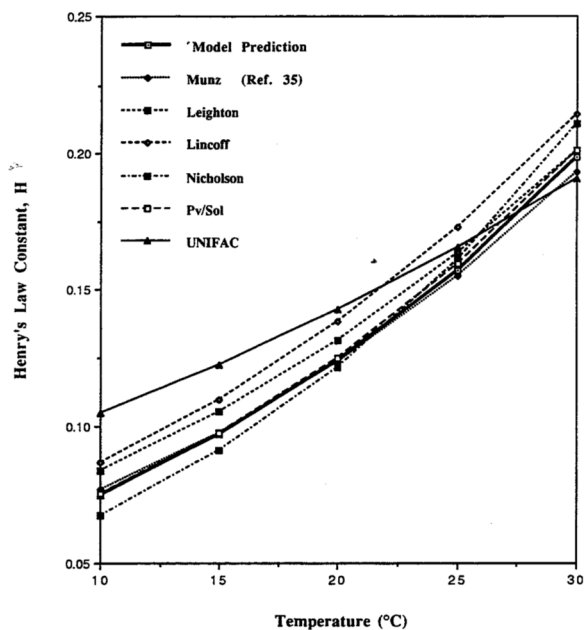
Trouton's rule (Reference 23, page 13-2), which is an approximation that gives ΔH_v at the boiling point, is used to estimate ΔH_v when T_c , P_c and Antoine's constants are missing:

$$\frac{\Delta H_{vb}}{T_b} = 21 \text{ cal/K} - \text{mole} \quad (40)$$

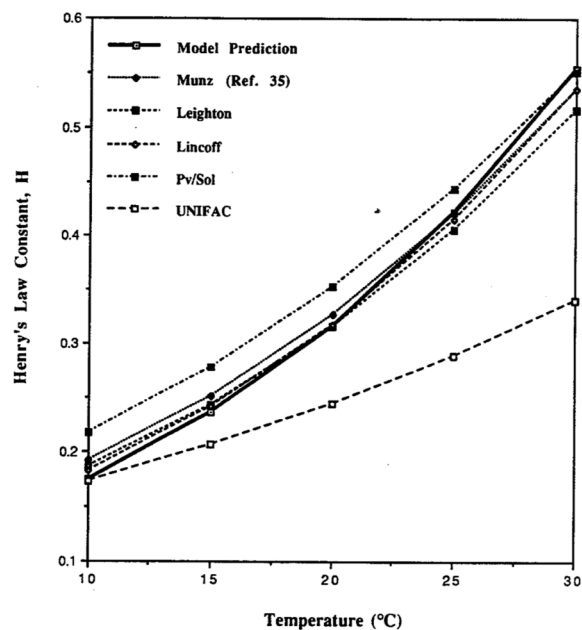
The compressibility factor difference (the left-hand side of Equation (37)) is estimated as 1.0 when Antoine's constants are available, but T_c and P_c are missing (Reference 23, Table 13-6). When only T_c values are missing, T_c is estimated as $1.5 \times T_b$ (Reference 23, page 14-13).

2.5.2 Validation of Temperature Dependency Algorithm

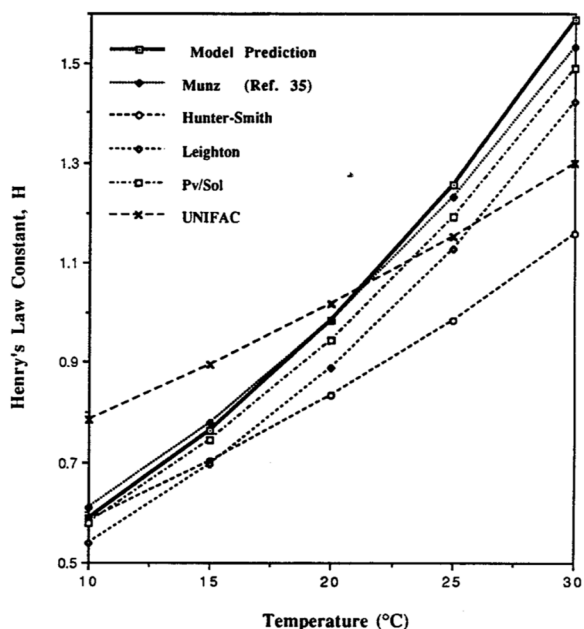
Munz and Roberts (Reference 35) reported the temperature dependency of the Henry's Law constant in the range of 10 to 30°C for bromoform, chloroform, trichloroethylene, tetrachloroethylene and carbon tetrachloride. The values from Munz's experiments and results from other experiments compiled by Munz were used for the validation of the method used in ASDC to describe the temperature dependency of H . The H value for each compound at 25°C was used as the basis for estimation of H at other temperatures. In Figure 7, H values for the four compounds are compared to the values measured at various temperatures. The Henry's Law constants predicted with the model incorporated in ASDC generally agree closely with the measurements of Munz and Robens (Reference 35) and others cited by them.



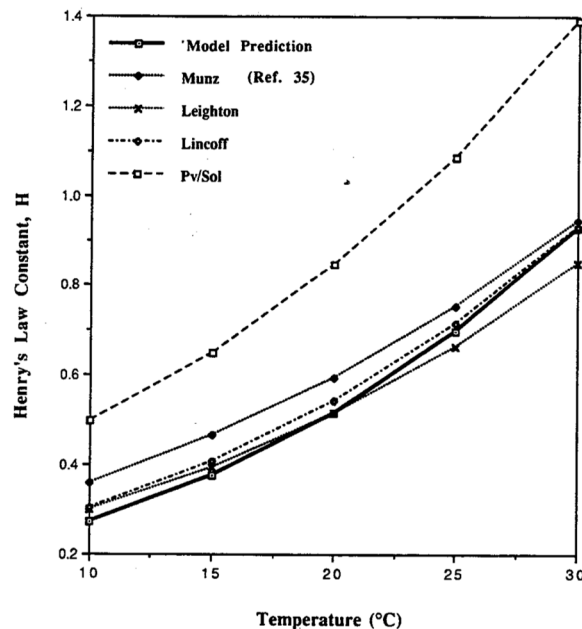
(a)



(b)



(c)



(d)

Figure 2-5. Temperature-Dependency of H for: (a) Chloroform, (b) Trichloroethylene, (c) Carbon Tetrachloride, and (d) Tetrachloroethylene

2.6 Design Air and Water Temperatures

Water temperature affects several parameters involved in air stripper design and operation, most importantly the Henry's Law constant and the mass transfer coefficient for the target VOC contaminants. The higher the water temperature, the greater the Henry's Law constant and the mass transfer coefficient. At higher water temperatures, lower air-to-water ratios may thus be employed. Effects of water temperature on H and K_{La} are considered in ASDC, as discussed previously.

The temperature of influent air has been found to have little effect on the performance of air stripping units. Gross and Termaath (Reference 2) evaluated air temperature effects in a full-scale system in which the inlet air temperature was varied systematically from 15 to 50°F. During these tests, no change in water temperature was detected along the packed column. In similar experiments with a pilot-scale column, Cummins (Reference 36) took water and air temperature measurements along the column and determined that the water temperature remained essentially constant and that air temperature adjusted rapidly to that of the water. These observations are consistent with basic thermodynamics. Straudinger (Reference 37) performed a heat balance calculation for a hypothetical air stripping system with an inlet air temperature of 0°F, an inlet water temperature of 55°F, and an air-to-water ratio of 20, and estimated that the water temperature would not change by more than 1°F.

In the ASDC program, the inlet water temperature is used as the design temperature upon which all the air, water, and contaminant property values are calculated. This approach is employed commonly in air stripper design.

2.7 Design Air and Water Properties

The basic properties of air and water used in the design of an air-stripping system, especially in estimation of K_{La} , are density and viscosity and, for water, surface tension. All these property values vary with temperature, though water viscosity exhibits the greatest sensitivity to temperature. It increases by approximately a factor of two from 10°C to 30°C. The ASDC program contains functions that can estimate the values for the air and water properties at different temperatures.

Extensive data for water density as a function of temperature are available. In Perry's Chemical Engineers' Handbook (Reference 29), such data are given for 0 to 100°C. The following polynomial equation can fit these data well:

$$\rho_L = 999.85 + 6.1474 \times 10^{-2}(T) - 8.3633 \times 10^{-3}(T^2) + 6.6805 \times 10^{-5}(T^4) + 1.3095 \times 10^{-9}(T^5) \quad (41)$$

where ρ_L is water density in kg/m³ and T is the temperature in °C. Equation (41) is incorporated in ASDC for estimation of ρ_L .

Estimation of water viscosity as a function of temperature is performed in ASDC using data fitting equations from the CRC Handbook of Chemistry and Physics (Reference 38):

for 0°C < T < 20°C:

$$\log \mu_L = \frac{1301}{998.333 + 8.1855(T - 20) + 5.85 \times 10^{-3}(T - 20)^2} - 1.30233 \quad (42)$$

for 20°C < T < 100°C:

$$\log \frac{\mu_L}{\mu_{20}} = \frac{1.3272(20 - T) - 1.053 \times 10^{-3}(T - 20)^2}{T + 105} \quad (43)$$

where μ_{20} is the water viscosity in centipoise at 20°C and T is the temperature of interest in °C. To convert centipoise to kg/m-sec, multiply by 0.001.

The dependence of water surface tension on temperature is also described using an equation for data in the CRC Handbook (Reference 38):

$$\sigma_L = 75.712 - 0.14475 \times T - 2.352 \times 10^{-4}T^2 \quad (44)$$

where σ_L is water surface tension in dyne/cm and T is the temperature of interest in °C. Equation (44) is valid for 0°C to 100°C. To convert dyne/cm to kg/sec², multiply by 0.001.

Air density and viscosity values for temperatures in the range of 0 to 100° C are given in the CRC Handbook (Reference 38) and Roberson and Crowe (Reference 39). The following equations describe these data accurately and are incorporated in ASDC:

$$\rho_G = 1.2926 - 4.6769 \times 10^{-3}T + 1.3986 \times 10^{-5}T^2 \quad (45)$$

$$\mu_G = 1.71 \times 10^{-5} + 5.0 \times 10^{-8}T \quad (46)$$

where ρ_G is air density in g/L or kg/m³, μ_G is air viscosity in N.sec/m², and T is the temperature of interest in °C.

3 Cost Model

3.1 Introduction

A cost model is incorporated in the ASDC program to give an approximate indication of the costs associated with a design. In many cases, capital and operating costs will not be the only considerations involved in the selection of an optimal design. Designs less than optimal with respect to total costs may be needed to provide flexibility for possible changes in influent characteristics or flow rate, to provide operational simplicity, or to fulfill any of a number of design goals other than the minimum cost. However, capital and operating costs will always be design considerations, if for no other reason than to quantify the price of meeting noneconomic design criteria.

The cost model incorporated in ASDC is not intended to provide a highly accurate estimate of the cost of a particular system, but rather to enable comparison of approximate costs for different designs on a consistent basis. Major capital and operating costs are evaluated using cost data and estimation methods obtained from manufacturers and from engineering literature. System costs are evaluated by summing the component capital and operating costs. An alternative approach is to estimate whole system cost by empirical correlation with total costs for existing systems of similar size (e.g. References 40-43). The component-by-component approach was selected because (1) system costs exhibit variability due to site-specific factors, (2) the component approach enables identification of key cost factors, and (3) single component cost information is easier to update.

An outline of the capital and operating costs considered in the cost model is provided. Estimation of direct capital costs (excluding electrical equipment and control system costs) depends on equipment sizes and material quantities and is performed for a given design on the basis of unit prices in the cost data base. For indirect capital costs and electrical/control equipment, coarse but generally accepted estimation methods are employed. The chief operating costs for an air stripping unit are the energy costs for the water pump and the air blower. Power cost estimation is performed using the operating characteristics for the particular pump and blower selected by the program for a particular design. Key assumptions necessary for estimation of labor and maintenance costs are requested from the user. Costs included in the cost data bases are referenced to 2019 and can be

adjusted in the program for inflation through use of the Engineering News Record (ENR) Construction Index. Detailed descriptions of the components of the cost model are provided below.

3.2 *Standard Air Stripper Configuration*

Construction considerations vary from site to site and, therefore, an assumed standard configuration of the air stripping system is employed in the cost model. This is done to provide internal consistency in the cost estimates for alternative designs. The assumed configuration, shown in Figure 3-1, contains the basic process and support equipment required for a single tower system. It includes the column shell, column internals (i.e., liquid distributor, liquid redistributor(s), and packing support plate), random packing material, mist eliminator, one centrifugal pump, and one centrifugal fan. A constant suction head loss to the water pump of 5 feet is assumed. Support equipment considered includes a 15 ft x 15 ft x 4 ft concrete foundation, steel piping (with a valve and flow meter) from the pump discharge to the top of tower, 100 feet of field piping to the pump, 10 feet of stainless steel air duct (with a damper and a flow meter) from the blower discharge directly to the base of the tower, a gas pressure measurement device at the air inlet and outlet locations in the tower, and a simple manual switch-on electrical power and control system.

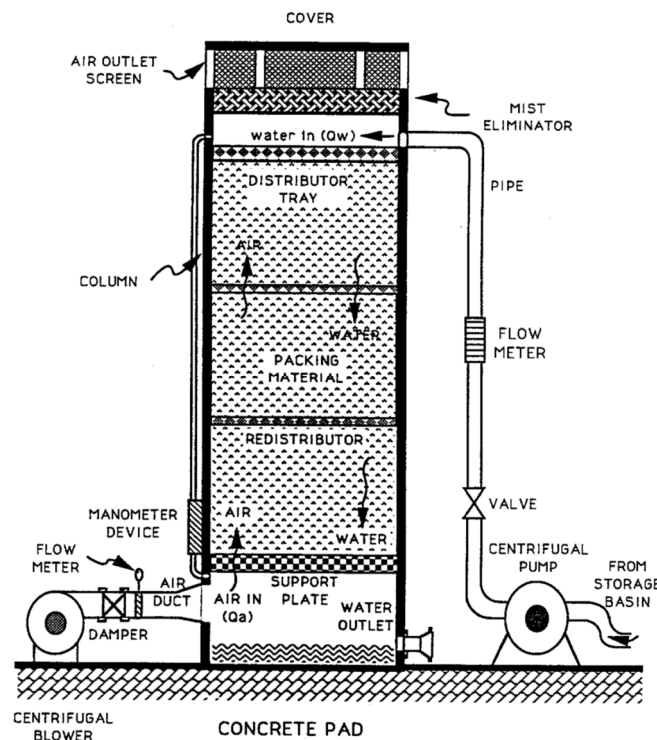


Figure 3-1. Standard Air Stripping Configuration

3.3 Direct Capital Costs

The direct capital cost includes all the physical items required for installation of an air stripping tower, that is, process and support equipment costs. The process equipment cost is the key component of the cost model. Process equipment includes the column shell, column internals (i.e., liquid distributor, liquid redistributor, and packing support plate), packing material, air blower, water pump, and mist eliminator. Equipment size requirements calculated in the design procedure are used to determine the quantity of material involved with a particular design.

3.3.1 Column Shell

The cost of the column shell is one of the key components of the tower direct cost. Column shells typically are constructed using aluminum or corrosion-resistant steel, predominantly the former. Generic cost data for air stripper column shells are difficult to obtain since they are often custom fabricated. Some very approximate prices for aluminum column shells were provided by one leading manufacturer of air stripper systems. These prices were compared to prices for standard pressure vessels in Richardson Process Plant Construction Estimating Standards (Reference 44, Sections 100-341 to 100-362) and it was found that the approximate column prices were similar to those for pressure vessels constructed with A-285 and A-515 pressure-vessel-quality steel plate. As is the case for an air stripping column shell, the cost of a pressure vessel depends on its height and diameter. A general expression is given in the Richardson Standards for the cost of the pressure vessels cited above:

$$C_{column} = (45.2 + 3.5D_i - 7.7 \times 10^{-3}D_i^2) \times H_{tower} \quad (47)$$

where D_i is the column diameter in inches and H_{tower} is the column total height in feet. (The result is multiplied by 2.0 in the program to update the cost to 2019.) This expression is used in the ASDC program to estimate the base cost of an aluminum column shell.

The cost for the column shell itself is related with the total height of the column. The total height of the column is the sum of the packing material height, the height of the column skirt which accommodates the air duct inlet and treated water outlet, and the height of the column top for the water pipe inlet, liquid distributor, mist eliminator, and some other devices (e.g., connection to off-gas treatment). As the sizes of these accessories vary, determination of the total height of the air stripping tower requires some assumptions. The ASDC program assumes that the total height is given by the packing height plus some fraction of the packing height. From careful examination

of several air stripper designs, it was determined that the multiplication factor is a function of the water flow rate. The multiplication factors employed in ASDC for determining total column height are given in Table 3-1.

Table 3-1. Packing Height Multipliers for Estimating Total Column Height

Water Flow Rate (gpm)	Packing Height Multiplier
< 500	1.30
500 – 1000	1.40
1000 – 1400	1.45
1400 – 1800	1.50
> 1800	1.60

To estimate the total cost of the column shell, the cost of shell accessories must be considered along with the cost of the shell itself. As shown in Figure 3-1, the assumed configuration of the column shell includes two access ports for maintenance, one pipe inlet, one air duct inlet, one water outlet, and some open nozzles for instrument devices. The costs for all of these items depend on size and quantity.

The access ports are assumed to be of the same material as the column shell. The assumed access port type, a long weld neck-type radial nozzle, is illustrated in Figure 3-2. In ASDC, access ports ranging in size from 2 to 24 inches in diameter are considered and the following equation from the Richardson Standards (Reference 44, Section 2 100-348) is used to estimate access port cost:

$$C_{port} = -31.6 + 72.8D_m - 2.8D_m^2 + 0.11D_m^3 \quad (48)$$

where D_m is the diameter of the access port in inches. (The result is multiplied by 2.0 in the program to update the cost to 2019.) The size for the port is determined in relation to the diameter of the column. The ASDC program chooses the largest available size that does not exceed two-thirds of the column diameter up to a maximum 24 inches.

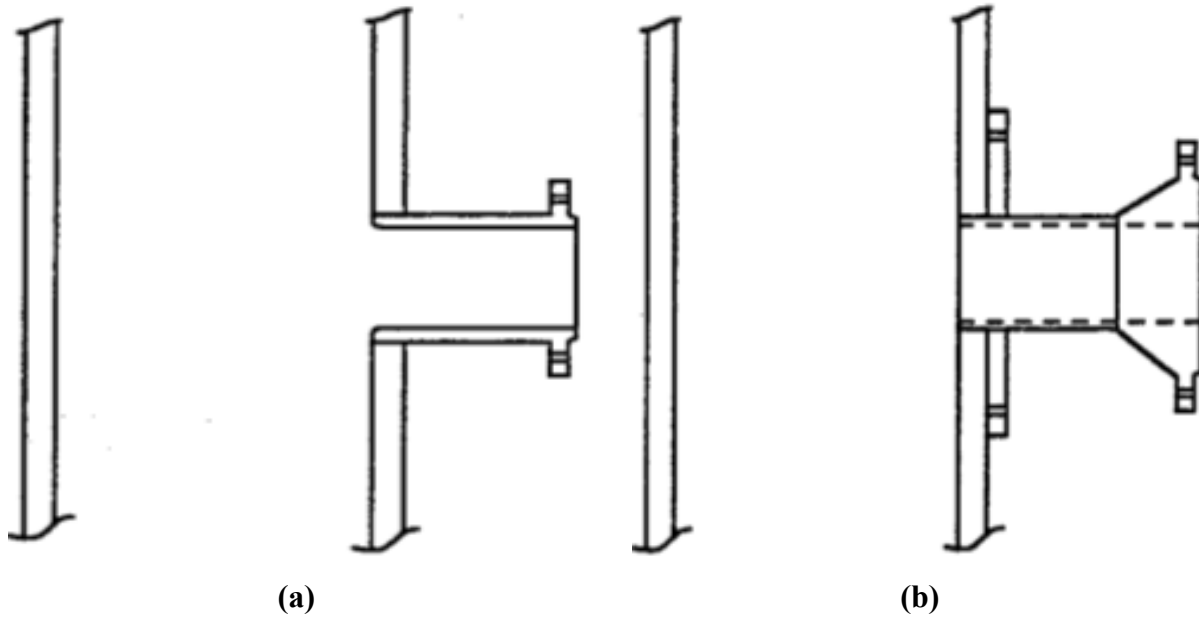


Figure 3-2. Column shell accessories assumed in standard configuration: (a) typical long-weld neck type nozzles, and (b) typical buttweld flange type nozzles

Costs for the water pipe inlet and treated water outlets are also estimated in ASDC using a correlation equation from the Richardson Standards (Reference 44, Sections 100-347 and 100-349) for buttweld flange-type nozzles:

$$C_{outlet} = 133.8 + 42D_p + 4.8D_p^2 \quad (49)$$

where D_p is the pipe diameter in inches. (The result is multiplied by 2.0 in the program to update the cost to 2019.) In ASDC the water inlet pipe size is the optimal pump discharge pipe size, discussed later in the section on water pump selection. The treated water outlet pipe size is determined by the same rules for choosing access port size. Estimation of cost for the instrument device nozzles also is performed using the above equation by considering six 2-inch or smaller nozzle openings. The cost for the air duct inlet is estimated using the cost equation for the access port and an additional five percent is added for the tangential shape of the air duct inlet.

Table 3-2. Design Contingency Overhead Multipliers for Total Column Cost

Total Column Cost (\$)	Design-Contingency-Overhead-Multiplier
< 6,000	1.25
6,000 – 8,000	1.24
8,000 – 10,000	1.23
10,000 – 15,000	1.22
15,000 – 20,000	1.21
20,000 – 25,000	1.20
25,000 – 35,000	1.19
35,000 – 50,000	1.18
50,000 – 75,000	1.17
> 75,000	1.16

Note 1: from Richardson (Reference 44), Section 100 – 358

In the assumed tower configuration, tray rings are used to support the liquid distributor and fiberglass-reinforced plastic (FRP) support plate. The number of tray rings used is discussed in the next subsection on column internals. Ring cost estimation is performed using a correlation equation from the Richardson Standards (Reference 44, Section 100-352):

$$C_{ring} = 70.4 + 4.45D_i + 1.73 \times 10^{-2}D_i^2 \quad (50)$$

where D_i is the column diameter in inches. (The result is multiplied by 2.0 in the program to update the cost to 2019.)

The total cost of the column shell is estimated by adding the shell accessory costs to the cost of the shell itself. A cost multiplier of approximately 1.2 (see Table 3-2) is added to the total column shell cost to account for engineering design, contingency, and overhead.

3.3.2 Column Internals

The column internals include one plate-type liquid distributor, wall-wiper liquid redistributors (for every 5 to 6 feet), and one FRP packing support plate. For packing height greater than 30 feet or the ratio of packing height to tower diameter greater than 10, another liquid distributor is included. The costs of these items are functions of diameter. Costs of FRP grid support plates were obtained from equipment vendors, while costs for orifice plate-type liquid distributor trays were taken from

the Richardson Standards (Reference 44, Sections 100-353 and 100-359). Correlations of cost versus diameter were developed as follows:

$$C_{tray} = 658.1 - 6.5D_i + 0.22D_i^2 \quad (51)$$

$$C_{plate} = 20.6 + 1.1D_i + 9.7 \times 10^{-2}D_i^2 \quad (52)$$

where C_{tray} is the cost for the liquid distributor, C_{plate} is the cost for the FRP packing support plate, and D_i is the column diameter in inches. (Both costs are multiplied by 2.0 in the program to update them to 2019.) The wall-wiper liquid redistributors are assumed to be 5 percent of the liquid distributor cost. The total cost for internals is obtained by summing these components and applying a factor of 1.2 for contingency and overhead.

To illustrate calculation of the costs of internals, consider a column with diameter of 5 feet (1.52 m) and packing height of 32 feet (9.75 m). The cost for the two liquid distributors required would be $\$1060 \times 2$, or \$2120. The cost for four wall-wiper redistributors would be $1060 \times 0.05 \times 4$, or \$212. The number of wall wipers is determined by the rule that if more than one distributor is used, consider one redistributor every 6 feet over half of the packing height. If only one liquid distributor is used, a redistributor is placed every 5 feet over the entire packing height. The cost of the FRP support plate would be \$436. Therefore, the total cost for the column internals, including the contingency factor, would be $(\$2120 + 212 + 436) \times 1.2$ or \$3322.

3.3.3 Packing Material

The cost for packing material is also one of the key components of the tower direct cost. This cost can be calculated readily with knowledge of the unit prices for different types of packing material. From contacting several packing material manufacturers ceramic, polypropylene packing materials were obtained. The unit costs incorporated in the program are listed in Table 3-3. Packing costs for materials other than polypropylene were determined using the polypropylene packing cost data in Table 3-3 and cost multiplying factors ascertained from manufacturers. The program provides users the flexibility to input cost information for specific packing material for more accurate estimation of packing materials cost.

Table 3-3. Average unit costs for polypropylene packing material (2020)

Packing Volume	Unit Packing Cost (\$/ft ³)
0 – 99	15
100 – 499	15
500 – 999	14
1000 – 1999	12
> 2000	10

3.3.4 Water Pump

An algorithm is included in the ASDC program to determine the pump type and size required for a particular design. This level of design detail is necessary for process capital and operating cost estimation. For pump sizing, the total head loss to be overcome and system flow rate must be known. Determination of the total system head requires knowledge of the pump discharge head loss which is related to the pump discharge pipe size. Therefore, pipe sizing is the first step in the algorithm.

Generally, the aim in designing a piping system is to transmit the desired flow rate at the lowest overall cost. The cost of the pipe and associated fittings is directly proportional to the pipe diameter. The energy cost of pumping is, however, inversely proportional to the diameter. Thus, an economic balance is needed such that the pipe diameter gives the minimum sum for capital and operating cost. To determine the optimum pump discharge pipe diameter, the ASDC program employs the methodology developed by Genereaux (Reference 45) and by Sarchet and Colburn (Reference 46); the approach is summarized in Reference 47. In this approach, the annual cost of pumping and the annual (amortized) cost of a unit length of pipe are combined and the pipe diameter that gives the minimum sum is selected. The power required in a year for pumping liquids is given by the product of flow rate (Q), pressure drop (ΔP), and duration of operation (Y):

$$Power = Q \times \Delta P \times Y = Q \left(\frac{4fLV^2}{2gD} \right) Y \quad (53)$$

where Y is the duration of operation per year, f is the friction factor ($0.4/N_{Re}^{0.16}$) for turbulent flow, N_{Re} is the Reynold number ($DV\rho/\mu$), D is the pipe diameter, ρ is the fluid density, μ is the fluid viscosity, V is the fluid velocity, L is pipe length and g is the gravitational constant

Over the course of a year, the cost of pumping may be obtained by considering the cost of electricity and the pump efficiency.

$$C_{pump} = Q \left(\frac{4fLV^2}{2gD} \right) Y \frac{K}{E} \quad (54)$$

where K is electricity cost (cost per KW-hr), E is efficiency of motor and pump and C_{pump} is the pumping cost per linear foot per year. For pipe sizing calculations, a combined efficiency of 0.5 is assumed in the program ($E = E_{pump} \times E_{motor} = 0.8 \times 0.6 = 0.5$).

Capital pipe cost must be considered as well as the associated operating cost. For most types of pipe, a plot of logarithm of the pipe diameter versus the logarithm of the purchase cost per foot is essentially a straight line. Therefore, the purchase cost for pipe may be represented by the following equation:

$$C_{pipe} = XD^n \quad (55)$$

where C_{pipe} is purchase cost of new pipe per foot of pipe length, X is the purchase cost of new pipe per foot for unit diameter, and n is the constant with value dependent on type of pipe. (The result is multiplied by 2.0 in the program to update the cost to 2019.)

The annual cost for the installed piping system may be expressed as follows:

$$C_{pipe} = (1 + F)XD^nK_F \quad (56)$$

where K_F is the amortized annual fixed cost, expressed as a fraction of initial cost, for installed pipe and F is the ratio of cost for fitting and installation to purchase cost of pipe.

Combining the annual operating cost (C_{pump}) and amortized capital cost (C_{pipe}) yields the total annual cost, C_T . The differential of C_T with respect to D may then be taken, set equal to 0, and the resulting expression solved from $D_{optimum}$, the economic pipe size. Various expressions for $D_{optimum}$ are summarized in Reference 47, Chapter 10; one of these (Equation 46) is implemented in ASDC for determination of the discharge pipe size.

Once the pump discharge pipe size is selected, the optimum pump size can be determined for different flow rates. In ASDC, the total system head is set at the pump discharge head loss plus the assumed 5 feet suction head loss and the static discharge head (the tower height). Determination of the optimum pump size is accomplished by the following procedure:

1. Determine the pump system head, h_{sys} .
2. For pumps (included in a database) that can handle the desired flow rate Q_w , and system head, h_{sys} . Scan the pump characteristic curve data for each pump to determine the pump efficiency at the specific operation point (Q_w, h_{sys}).
3. Choose the most efficient pump.

Characteristic curves for a number of variable speed centrifugal water pumps, with capacities from 150 gpm to 4000 gpm (for $h_{sys} < 100$ feet) have been obtained from several leading pump manufacturers. These characteristic curves have been described using polynomial fitting equations and included in a data base (see Appendix A). Pump selection is performed using this data base and the procedures discussed above.

Once a pump is selected, its capital cost is determined directly from cost information incorporated in the cost data base (see Table A-1 in Appendix A). When the flow rate is outside of the 150 gpm to 4000 gpm range, pump capital cost is estimated via a simple extrapolation procedure that utilizes the available pump cost data. Pump capital cost is estimated by applying a multiplier to the capital cost for either the 150 gpm or the 4000 gpm pump that reflects the proportional flow below 150 gpm or above 4000 gpm. For a flow Q_1 less than 150 gpm, the pump capital cost is estimated as $C_{pump, Q_1} = C_{pump, 150} \times (Q_1/150 \text{ gpm})$. At a flow Q_2 above 4000 gpm, $C_{pump, 4000}$ is multiplied by the factor $Q_2/4000 \text{ gpm}$.

Pump operating cost (discussed later) is calculated using the efficiency for the operating condition and determined in the pump selection routine, except when the flow rate is outside the range of available data. For water flow rates less than 150 gpm and greater than 4000 gpm, a pump efficiency of 70 percent is assumed.

3.3.5 Air Blower

An algorithm is included in ASDC for determination of air blower type and size for a particular design. As in the case of the water pump, detailed blower design is necessary for capital and operating cost estimation.

Air blower size is determined by the system static pressure drop and the air flow required which depends on the air/water ratio. The system air pressure drop is the sum of the pressure drop over the tower plus the pressure drop over the equipment (e.g., air duct, support plate, liquid distributor, and mist eliminator). A value of 1.5 in-H₂O is assumed in the program for the pressure drop over the equipment; pressure drop over the packing is specified by the user (i.e., ΔP). Fan capacity tables for a number of variable speed centrifugal air blowers, with capacity ranging from 200 cfm up to approximately 40,000 cfm (for ΔP up to 10 in-H₂O), have been obtained from a leading blower manufacturer. These tables are included in a data base in ASDC which is scanned for determination of the appropriate fan size. The tables are given in Appendix B. Blower selection is accomplished in ASDC by the following procedure:

1. Determine the system static pressure drop, ΔP .
2. Calculate the required air volume from air loading rate, tower area and the density of air.
3. For blowers (included in a database) that can handle the desired air volume, Q_a and ΔP , scan the fan capacity tables for each blower to determine the blower efficiency at the specified operation point ($Q_a, \Delta P$).
4. Choose the most efficient blower.

Once a blower is selected, its capital cost is determined directly from cost information incorporated in the cost data base (see Table B-1 in Appendix B). When the blower flow rate is outside the range of available data (200 cfm to 40,000 cfm), blower capital cost is estimated using the same extrapolation procedure described for estimation of pump capital costs at high and low flow rates. For an air flow Q_1 less than 200 cfm, C_{blower, Q_1} is estimated by multiplying $C_{blower, 200}$ by $Q_1/200$ cfm. At a flow Q_2 greater than 40,000 cfm, $C_{blower, 40,000}$ is multiplied by $Q_2/40,000$ cfm.

Blower operating cost (discussed later) is calculated using the efficiency for the operating condition and particular blower determined in the blower selection routine, except when the flow rate is outside the range of available data. For air flow rates less than 200 cfm or greater than 40,000 cfm, a blower efficiency of 70 percent is assumed.

3.3.6 Mist Eliminator

The mist eliminator is assumed to be stainless steel mesh type, 4 inches in thickness. Its cost is estimated using data given in the Richardson Standards (Reference 44, Section 100-360). The correlation developed for the demisting pad and associated bottom grid is:

$$C_{mist} = 1.2 \times (46.4 + 9.3D_i + 0.14D_i^2) \quad (57)$$

where D_i is the tower diameter in inches and the constant 1.2 is the multiplier assumed for contingency and overhead. (The result is multiplied by 2.0 in the program to update the cost to 2019.) The correlation is based upon data for mist eliminators with diameters varying from 36 to 144 inches.

3.3.7 Support Equipment

Ancillary equipment needed for connection of the major process equipment components includes piping and air ducts, and electrical control equipment. In ASDC, costs for these support equipment items are estimated as percentages of the total process equipment cost. Pipe and air duct costs are estimated as 20 percent of the total process equipment cost plus the cost of piping from the water pump discharge to the top of the column. For the discharge piping cost, the optimum pipe diameter is estimated as described in subsection 3.3.1; the pipe length is given by the column height, and unit prices for steel pipe are taken from Richardson Standards (Reference 48, Section 15). Electrical system cost is estimated as 10 percent of total process equipment cost. This fraction is representative of basic electrical control system costs (References 47, 48, 49); it is not intended to include the cost of elaborate instrumentation.

3.4 Indirect Capital Costs

Indirect capital cost includes all nonphysical items required for an air stripping system. The indirect capital costs considered in the ASDC program include site work, engineering design, construction, and contingency and profit. The cost estimates for each of these items are based on percentages of the total direct cost, the approach most commonly used for estimation of indirect costs. Percentages used in the program for site work, design, and construction are 15 percent, 27 percent, and 20 percent, respectively. These percentages include contractor profit and overhead and were selected after review of cost estimating procedures for various water treatment technologies (e.g., References 49, 50). Actual percentages will be site specific but use of a single

set of percentages in the program provides internal consistency in cost estimates for alternative designs.

3.5 *Operating Costs*

The main operating cost associated with operation of an air stripper is the energy cost for electrical power to drive the water pump and the air blower. Power costs are based on the projected volume of water to be treated in a year and the electrical power consumed therewith. Energy requirements for treatment in a packed tower depend on the liquid and gas flow rates and associated friction losses. Once these have been calculated and a particular blower and pump have been selected, estimation of power consumption is straightforward.

Other operating costs include maintenance costs (cleaning of the tower, pump and blower maintenance, etc.), labor costs, and administrative costs. Labor cost may be included with maintenance cost or estimated separately. These costs are usually calculated on the basis of water volume treated. Administrative cost may be estimated as the sum of fractions of labor and maintenance costs, but it is usually not significant and hence is not considered explicitly in the ASDC program.

3.5.1 Power Cost

The power cost is based on the projected volume of water to be treated per year and the electrical power consumed by the pump and the blower associated with the air stripping system. The pump power cost is based on the volume of water pumped per year, head loss through the pipes, pump efficiency, and motor efficiency. It can be expressed as:

$$C_{pump} = 0.746 \frac{Q h_{sys} Y}{3960 E_{pump} E_{motor}} \quad (58)$$

where C_{pump} is the pump operating power cost (\$/yr), Q is the average water flow rate (gallon/min), h_{sys} is the total system head loss (ft), Y is the electrical cost (\$/KW-hr), E_{pump} is the pump efficiency (%) and the E_{motor} is the motor efficiency (%).

In ASDC, pump efficiency is determined in the pump selection algorithm, as discussed above. The motor efficiency is assumed to be 60 percent.

The blower power cost can also be calculated using Equation (58) and is based on volume of air used per year, air pressure drops through the column and through the ducts, fan efficiency and motor efficiency. The air pressure drop is that through the packing plus that through the other column equipment and ducts. For the column internals other than packing, a pressure drop equal to 1 inch of water is assumed. The air volume is calculated from the design air-to-water ratio; the blower efficiency is determined in the blower selection algorithm. The cost of electricity is fixed by the user in the ASDC program.

3.5.2 Maintenance and Labor

The maintenance cost for an air stripping system will vary a lot from site to site. It depends significantly upon the chemistry of the inlet water which determines the likelihood of potential problems such as scaling or biofouling. Some existing full-scale systems have been operated without any serious problems, while other systems have experienced problems with clogged packing material after just a few months (e.g., References 2, 14). For internal consistency among cost estimates for alternative designs, 10 percent of the direct capital cost is assumed in ASDC for the maintenance cost. This method of estimating maintenance cost is common, and the percentage employed is typical (References 14, 43). The labor cost is based on a flat rate of 0.5 cent per 1000 gallon treated plus an add-on for the total volume of liquid treated per year.

3.6 Total Annual Cost

The total annual cost is estimated by summing the amortized capital cost and annual operating cost. The amortized cost is the total capital cost amortized over a particular time period at an interest rate. The total annual cost is given by the following equation:

$$\text{Annual Cost} = \text{Operating Cost} + \text{Total Capital Cost} \times \frac{1/100}{1 - (1 + I/100)^{-y}} \quad (59)$$

where I the annual interest rate in percent, and y is the time in years over which the capital costs are being amortized. Both the interest rate and time period can be specified by the user in the ASDC program.

3.7 Adjustment of Costs for Inflation

Costs in the ASDC cost data bases and calculated by ASDC are referenced to 2019. However, cost calculations including adjustment for inflation may be performed for any year with the program through use of the ENR Construction Cost Index. All costs estimated by ASDC are adjusted for

inflation using this index. Table 4 lists average values of the ENR Construction Cost Index for the years 1971-2019; the index value of interest is specified by the user in ASDC, with the default value being that for 2019.

Table 3-4. Average Annual ENR Construction Costs Index Values for 1971-2019

Year	Average ENR CCI Value	Year	Average ENR CCI Value	Year	Average ENR CCI Value
1971	1581	1991	4835	2011	9070
1972	1753	1992	4985	2012	9308
1973	1895	1993	5210	2013	9547
1974	2020	1994	5408	2014	9806
1975	2212	1995	5471	2015	10035
1976	2401	1996	5622	2016	10338
1977	2576	1997	5825	2017	10737
1978	2776	1998	5920	2018	11062
1979	3003	1999	6060	2019	11281
1980	3237	2000	6221		
1981	3535	2001	6342		
1982	3825	2002	6538		
1983	4066	2003	6695		
1984	4146	2004	7115		
1985	4195	2005	7446		
1986	4295	2006	7751		
1987	4406	2007	7967		
1988	4519	2008	8310		
1989	4615	2009	8570		
1990	4732	2010	8799		

Note: 1. Base Year = 1913; ENR CCI =100

4 Program Operation

4.1 Introduction

The Air Stripper Design and Cost (ASDC) for Windows program is intended to serve as an aid in designing an air-stripping unit for the removal of VOCs from water and wastewater. This program builds on a program developed in 1991 under a CMU contract with the U.S. Air Force. ASDC for Windows has been completely re-written but incorporates some code from the original program. The original ASDC program was written in C++ and developed for use with the DOS operating system.

ASDC for Windows is an interactive, menu-driven program written in Smart C++ language that can be run on computers with the Microsoft Windows operating system. A software product called DevExpress was used to create the graphics code in the ASDC for Windows program. The program can be run on Windows 8 or higher version of Windows operating system.

ASDC is based upon well-established procedures for design of counter-current air stripping units for water treatment. The program includes a cost model. Consideration of capital and operating costs enables evaluation of optimum designs with respect to cost.

This chapter describes the operation and functions of the ASDC for Windows program. There are two basic ways of running the program, referred to below as Standard Sequential Execution and Quick Start Execution.

While the ASDC program has been constructed with care, it is furnished “as is” and with absolutely no warranty, expressed or implied. The entire risk associated with the use of ASDC is with the user. All information generated by the program should be evaluated independently by the user as to its accuracy, completeness, reliability and suitability for any particular purpose.

4.2 System Requirements

4.2.1 Hardware

- Minimum Processor: 1 gigahertz (GHz) or faster x64-processor
- Minimum RAM: 4 GB
- Minimum Disk Space: 8 GB

4.2.2 Supported Operating Systems

The software requires a 64-bit operating system and is supported by Windows 8 x64, Windows Server 2016 x64, Windows Server 2019 x64, and Windows 10 x64.

4.3 Installation

The following is a step-by-step installation guide. Please note minor differences will exist depending on the operating system. The installation guide is prepared with a system running windows 10 64-bit.

Step 1: Run Installer



Figure 4-1. Screenshot of ASDC Windows setup wizard

Step 2: Press Next to Check Software Prerequisites

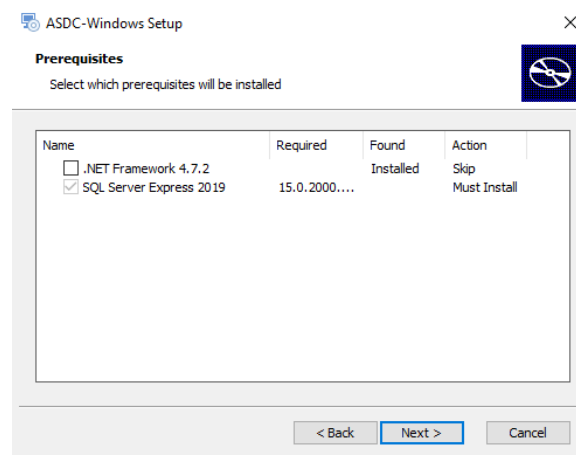


Figure 4-2. Screenshot of ASDC Windows setup prerequisites

Step 3: Start Installing Prerequisites by pressing the Next Button

Step 3-1: Allow Installation of Microsoft SQL Server 2019 Express by Pressing Yes Button



Figure 4-3. Screenshot of ASDC user account control

Step 3-2: Select a location for extracting installation files for SQL 2019 Express

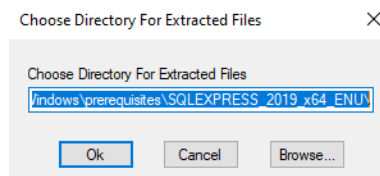


Figure 4-4. Screenshot of Directory chosen for extracted files

Step 3-3: Select to install a new SQL instance by pressing “New SQL Server stand-alone installation or add features to an existing installation” under “Installation”

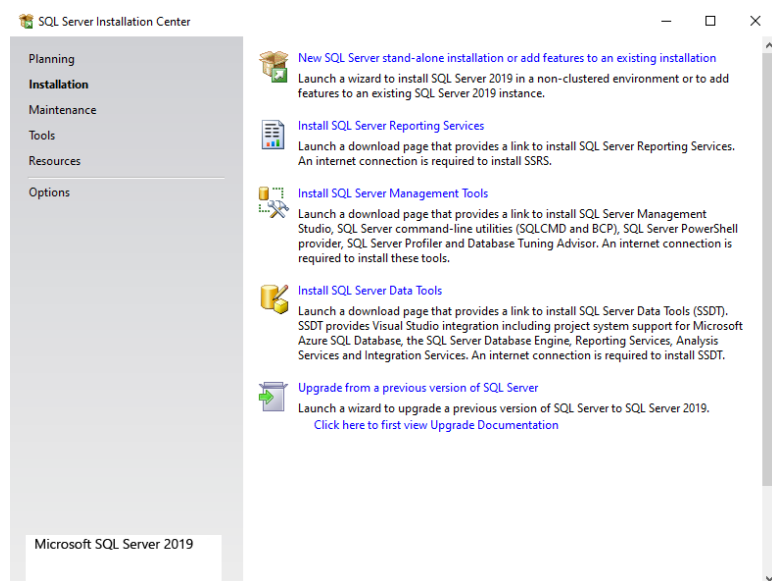


Figure 4-5. Screenshot of ASDC Windows - SQL server installation center

Step 3-4: Accept Microsoft Software License Terms

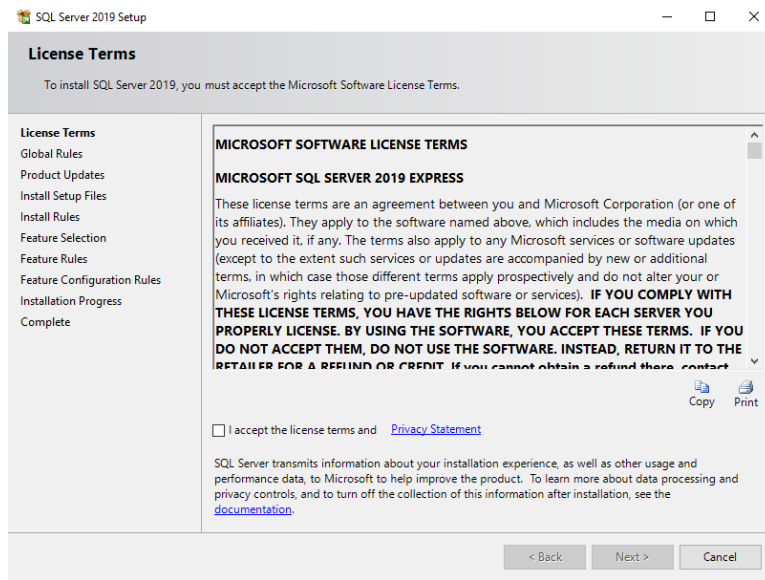


Figure 4-6. Screenshot of ASDC Windows - SQL license terms

Step 3-5: Check for SQL Server 2019 Updates and the press “Next”

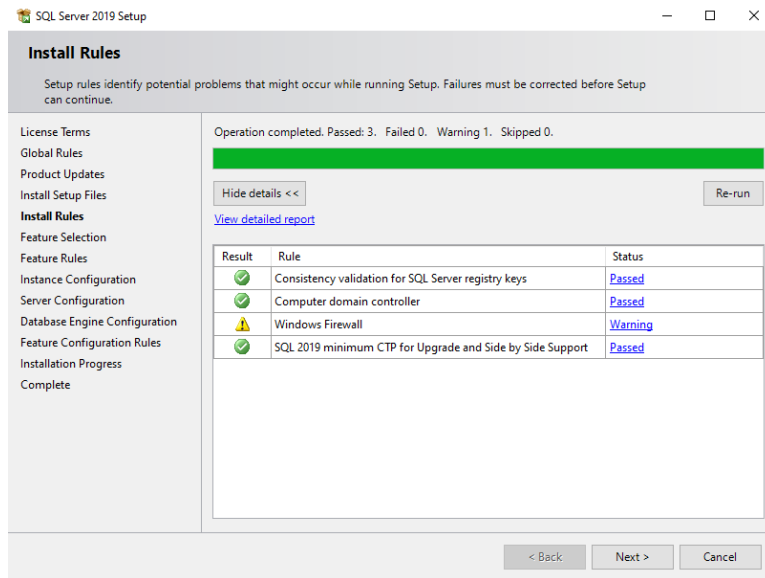


Figure 4-7. Screenshot of ASDC Windows - SQL server setup

Step 3-6: Select all instance features to be installed by pressing “Select All” and then “Next”

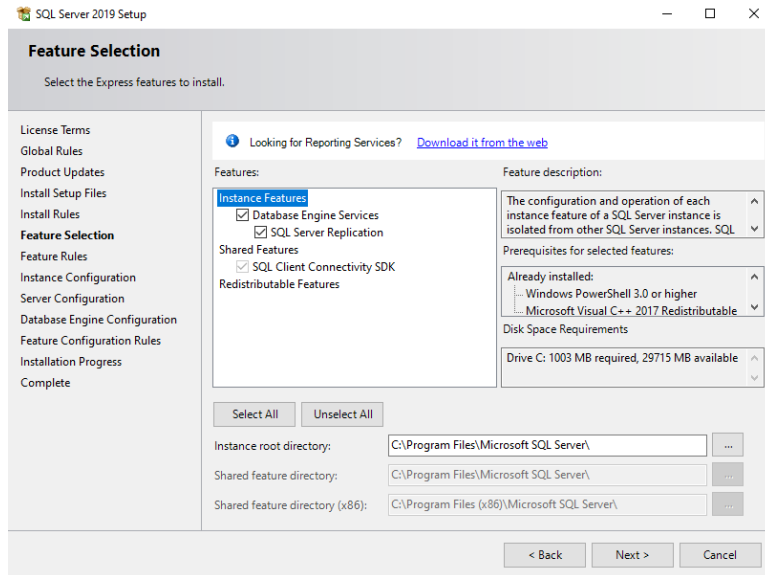


Figure 4-8. Screenshot of ASDC Windows - SQL feature selection

Step 3-7: Select an instance name for the SQL 2019 Server by default it is “SQLEXPRESS”, if other instances are installed, use a different instance name.

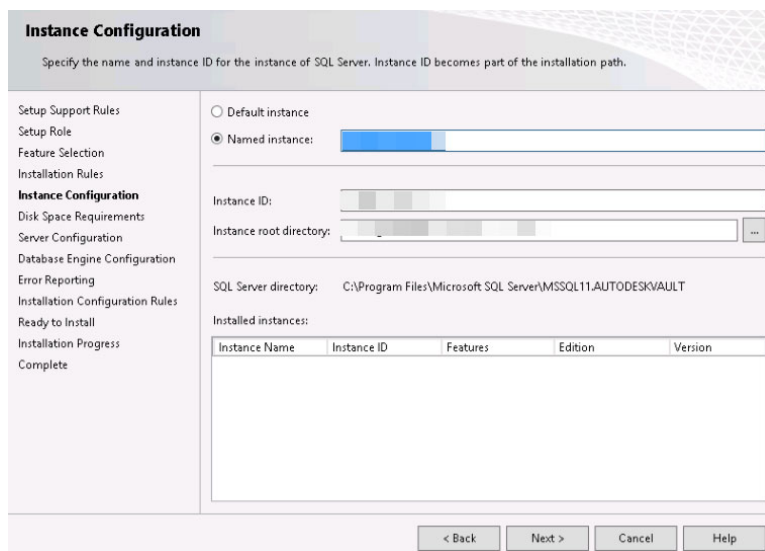


Figure 4-9. Screenshot of ASDC Windows - SQL instance configuration

Step 3-8: Keep default values under server configuration and press “Next”

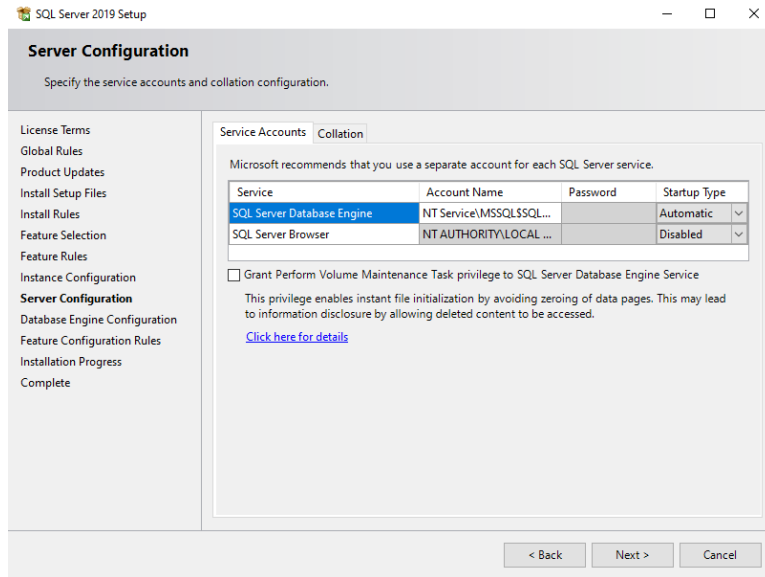


Figure 4-10. Screenshot of ASDC Windows - SQL server configuration

Step 3-9: Keep default values under Database Engine Configuration. If an administrator is not specified under SQL Server administrators, press “Add Current User” and the press “Next”

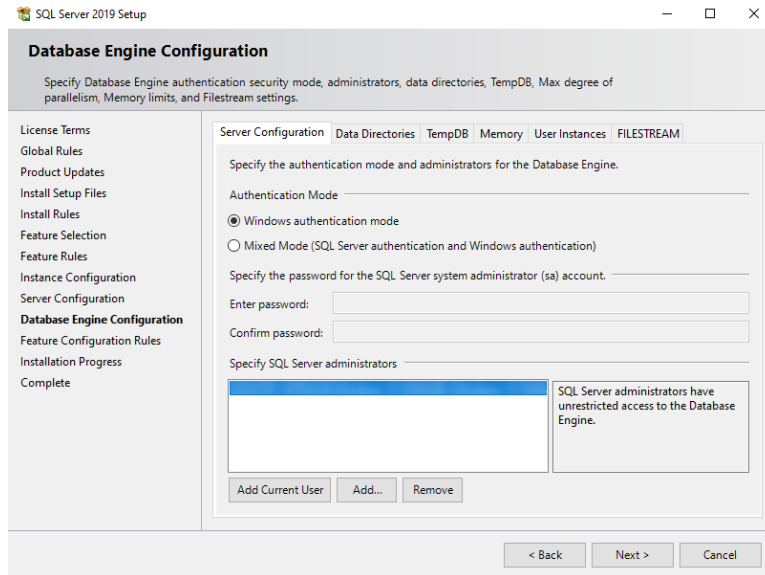


Figure 4-11. Screenshot of ASDC Windows - SQL database engine configuration

Step 3-10: Installation of SQL Server 2019 will initiate

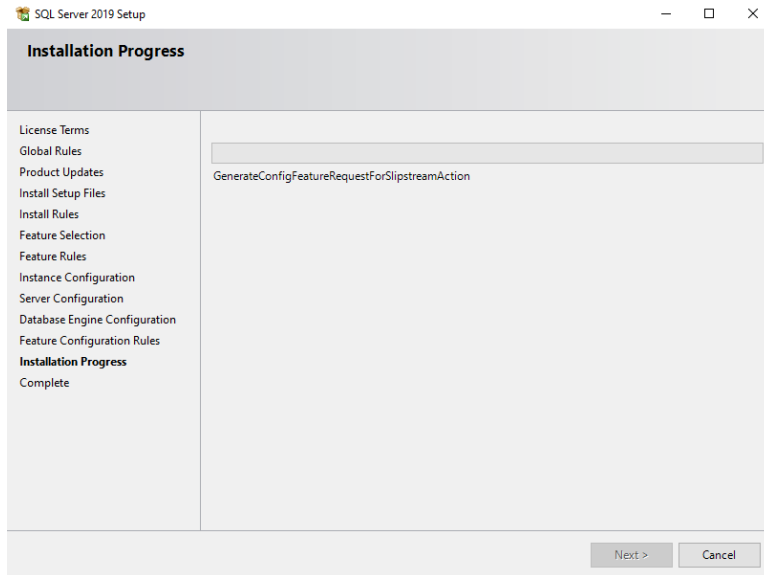


Figure 4-12. Screenshot of ASDC Windows - SQL server installation progress

Step 3-11: After SQL Server 2019 Installation is completed close the SQL Server Installation Main Menu by pressing the X (close) button located at the top right corner.



Figure 4-13. Screenshot of ASDC Windows - SQL server installation setup

Step 4: After the installation of the prerequisites, the ASDC-Windows setup welcome screen will pop-up. Press “Next” to continue the installation

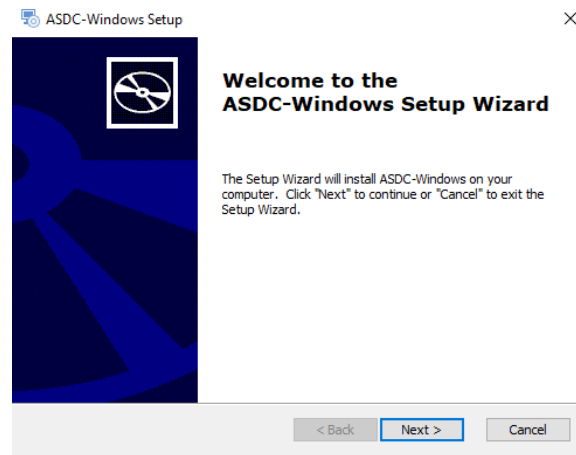


Figure 4-14. Screenshot of ASDC Windows setup wizard

Step 5: Please accept the end-user license agreement to continue with installation and then press “Next”

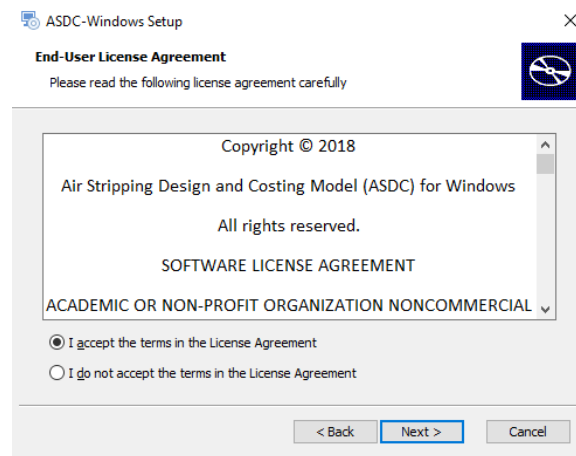


Figure 4-15. Screenshot of ASDC Windows license agreement

Step 6: Select an installation directory for the ASDC-Windows and then press “Next”

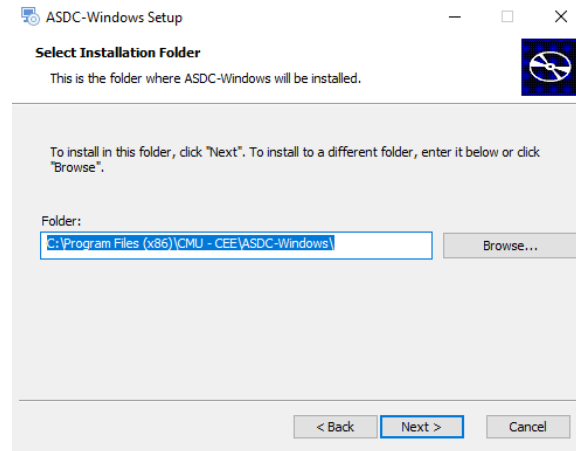
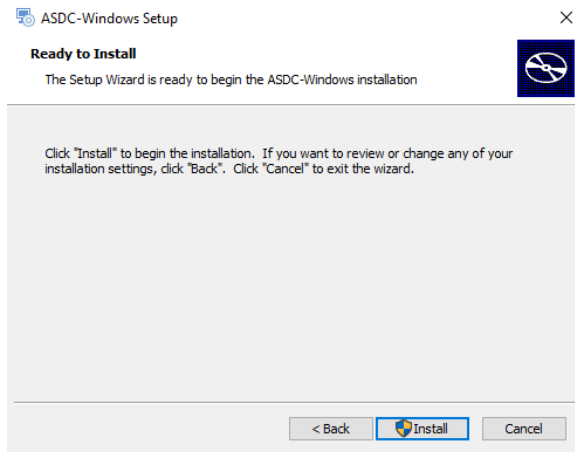
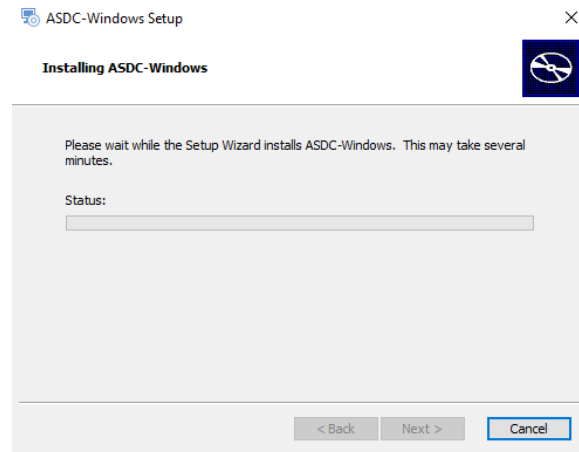


Figure 4-16. Screenshot of ASDC Windows setup installation folder

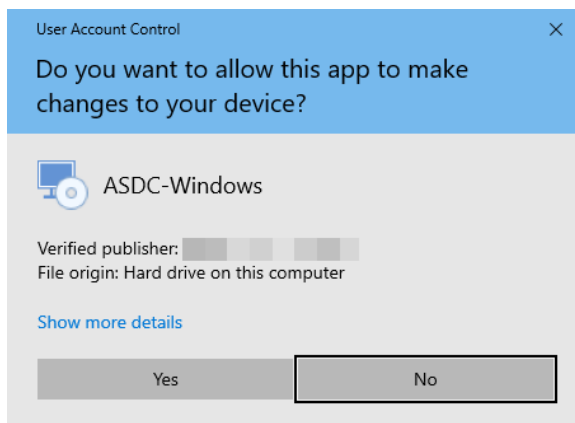
Step 7: Install the software by pressing the “Install” button and accepting the setup to make changes to your device by selecting “Yes” on the “User Account Control” screen.



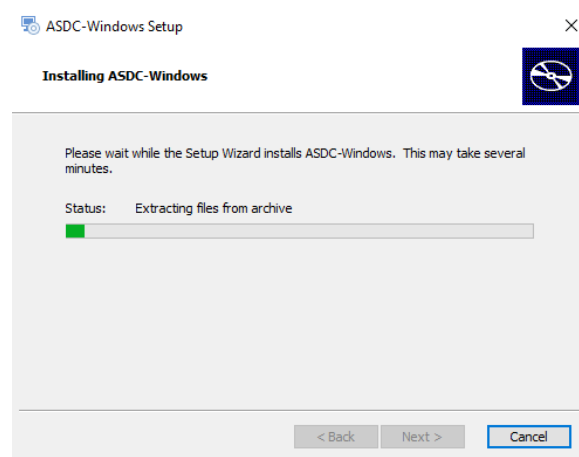
(a)



(b)



(c)



(d)

Figure 4-17. Screenshots for step 7 of the installation of the ASDC-Windows: (a) installing ASDC windows after prerequisites are installed and program location was selected, (b) installation is preparing package, (c) accept changes to your device and (d) setup extracts necessary files

Step 8: Close setup screen once installation is done by pressing the “Finish” button at completion screen.

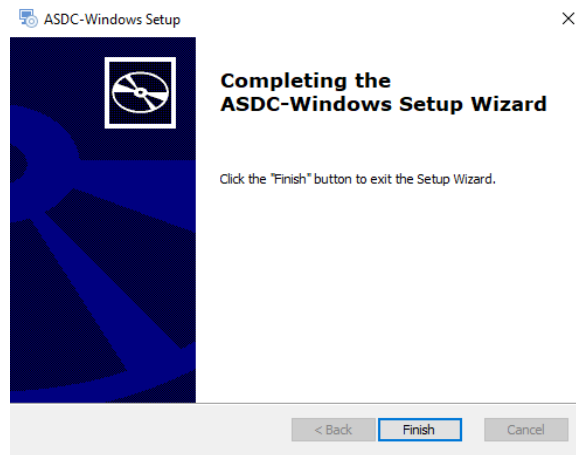


Figure 4-18. Screenshot of ASDC Windows installation setup wizard

4.4 Program Functions

The ASDC for Windows program has interactive menus and on-screen help and instructions, making most operations self-explanatory. When guidance is needed, the Operation Manual can be accessed by pressing the HELP function tab which will result in a drop-down menu consisting of Manual and details about the License agreement.

4.4.1 Standard Sequential Execution

The home screen of the ASDC for Windows program consists of various tabs in series which allows the user to enter the data and select the scenario for which they would like the design and estimate the cost.

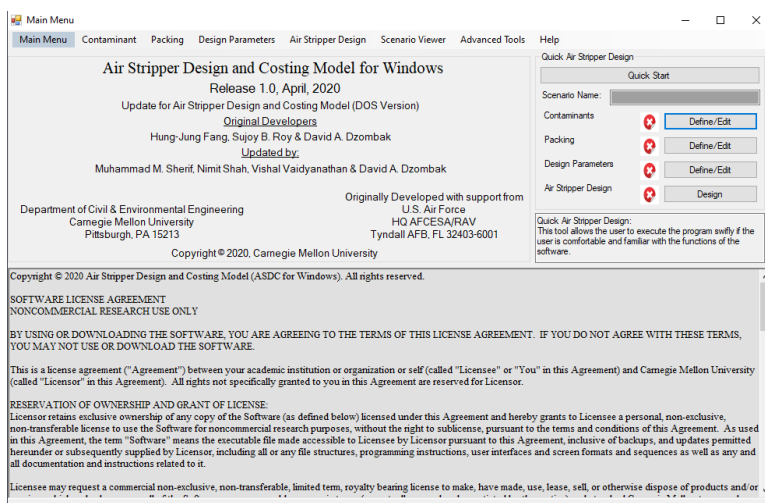


Figure 4-19. Screenshot of ASDC home screen

4.4.2 New Scenario Specification

This function enables specification of the new scenario upon which the air stripper design is named. A new scenario can be started from either the contaminant tab or the packing tab or design parameter tab. The users are provided with an option to start a scenario from any of three tabs as mentioned above and then carry on the program by adding other data.

4.4.3 Starting a New Scenario with Contaminant Selection

The contaminant can be selected by starting a new scenario and then entering the concentrations of the influent and effluent streams. Selection of compounds is performed by scrolling through the contaminant drop down menu list and pressing the left mouse key to select. The program permits a selection of up to 10 contaminants. Once all contaminants of interest have been selected, the user inputs the inlet concentration and the desired outlet concentration for each of the selected

contaminant. Then the user saves the scenario details using the ‘Save’ function. This enables the user to access and modify changes to the design criteria specified in the program. Next step is to select the packing material which can be done using the edit menu in the packing tab.

The screenshot shows the 'Contaminants Select' window. The 'Contaminant' tab is selected in the menu bar. The 'Select Contaminants' section on the left contains a table with columns for 'Contaminant', 'Influent Concentration (ppb)', and 'Effluent Concentration (ppb)'. The 'Contaminants Properties' table on the right lists various contaminants with their formulas, molecular weights, and boiling points. The 'Scenario Parameters' table at the bottom right has columns for 'Scenario Name', 'Packing Name', 'Flow Rate (gpm)', and 'Water Temperature (°C)'.

Contaminant Name	Contaminant Formula	Molecular Weight (g/mol)	Boiling Point
Acenaphthene	C12H10	154.2100000000	
Acenaphthylene	C12H8	152.2000000000	
Acetone	C3H6O	58.0900000000	
Acrolein	C3H4O	56.0600000000	
Acrylonitrile	C3H3.5N	53.0600000000	
Aldrin	C12H8Cl6	364.9200000000	
Aniline	C6H7N	93.1200000000	
Anthracene	C14H10	178.2400000000	
Benzene	C6H6	78.1100000000	
Benzonitrile	C7H5N	105.1200000000	

Scenario Name	Packing Name	Flow Rate (gpm)	Water Temperature (°C)

Figure 4-20. Screenshot of contaminant – new scenario

In the packing tab, the user goes to the edit menu and selects the packing material after loading the scenario entered. The complete description is provided in the Section 4.4.8.2 under the editing scenario.

After choosing the packing material, the design parameters are to be given by the user which can be done by going to the edit menu under the design parameter tab, loading the scenario and entering the parameters as described in the Section 4.4.8.3 under the editing scenario.

4.4.4 Starting a New Scenario with Packing Material Selection

This function enables selection of a packing material and its properties for subsequent air stripping design calculations. Approximately 60 different packing materials available from several manufacturers (Ceilcote, Glitsch, Jaeger, Koch, Lantec and Norton) are listed in a dropdown menu list. Selection of a packing material is performed by loading the scenario to display the contaminants saved during the previous step and scrolling through the dropdown menu and clicking on the packing material of interest. Only one kind of packing material can be specified for a scenario. After selecting a packing material click on ‘Save’ to save the selected packing material to the design scenario. The selected packing material will be displayed in the Scenario Properties table displayed on the top-right corner of the ASDC for Windows program screen.

Properties reported by manufacturers of the various packing materials have been compiled in a database and are displayed in the bottom-right corner of the ASDC for Windows program. A critical surface tension value of 61 dynes/cm is used for ceramic packings and a value of 33 dynes/cm for all the other packings.

After creating a new scenario with a packing material, we can go to the contaminant or design parameter menu and input the contaminant and the design parameters in the edit tab of the respective menu options as described in Sections 4.4.8.1 and 4.4.8.3 respectively.

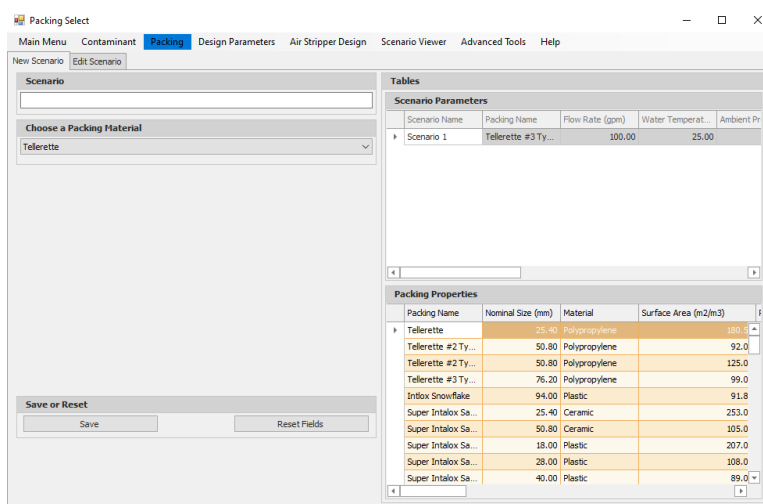


Figure 4-21. Screenshot of packing – new scenario

4.4.5 Starting a New Scenario with Design Parameters

This function specifies the values for important design parameters to perform the design calculations for removal of the specified contaminants using the selected packing material. Upon selection of the 'Design Parameters' tab the user clicks on the 'New Scenario' tab and types the Scenario for which the contaminants and packing materials have to be selected.

The user then specifies the water flow rate, water temperature, ambient air pressure and ranges of the variable design parameters R (stripping factor) and ΔP (gas pressure drop). A default value of 1.2 is recommended for the K_{La} safety factor and hence is already available in the field. After all the design parameters have been specified click on 'Save' to save the values to the selected scenario. The selected design properties can be seen in the Scenario Properties table on the top right-hand corner of the ASDC program screen. Select 'Reset Fields' to clear any unsaved changes made to the design parameters for the specified scenario.

For selecting the main design contaminant, the ASDC software performs a set of design calculations for the compound having the highest NTU (Number of Transfer Units) and R (Stripping factor) greater than 1. The protocol used to select the design contaminant is explained in Section 2.2.

After creating a new scenario under the design parameter tab with the design parameters entered by the user, contaminant and packing material needs to be selected by the user. This is done by going to the edit tab under the contaminant and packing menu, loading the scenario created and inputting the contaminant to be treated and the packing material to be used in the design respectively. For detailed description, refer to Sections 4.4.8.1 and 4.4.8.2 for selecting contaminant or packing material respectively.

The screenshot displays the 'Design Parameters' window of the ASDC software. The interface includes a menu bar with options: Main Menu, Contaminant, Packing, Design Parameters (active), Air Stripper Design, Scenario Viewer, Advanced Tools, and Help. Below the menu bar are three sub-tabs: New Scenario, Edit Scenario, and Main Contaminant. The 'New Scenario' sub-tab is active, showing a 'Scenario' name input field. The 'Scenario Properties' section contains several input fields: Flow Rate (with a unit dropdown set to 'gpm'), Water Temperature (set to '25' with a unit dropdown set to '°C'), Ambient Pressure (set to '1' with a unit dropdown set to 'atm'), Stripping Factor (with 'to' and 'by' sub-sections), ΔP (N/m²m) (with 'to' and 'by' sub-sections), and Safety Factor KLa (set to '1.2'). At the bottom of this section are 'Save' and 'Reset Fields' buttons. On the right side, the 'Scenario Parameters' table is visible, containing one entry:

Scenario Name	Packing Name	Flow Rate (gpm)	Water Temperat...	Ambient
Scenario 1	Tellerette #3 Ty...	100.00	25.00	

Figure 4-22. Screenshot of design parameter – new scenario

4.4.6 Air Stripper Design

After selecting the contaminant, packing material and the design parameters, the user chooses the air stripper design by loading the scenario for which the air stripper is to be designed under the “Air Stripper Design” tab. Specify the design contaminant or press the ‘AutoSelect’ option for the program to select the most appropriate contaminant based on the NTU value and the stripping factor, using the protocol explained in Section 2.2. Select a file name and folder for where the report is to be saved.

For the cost calculations, the time span and interest per year are given by default as 20 years and 10%, both of which can be altered by the user. Check the required boxes from the six options provided and click the ‘Design Air Stripper’ button.

Figure 4-23. Screenshot of air stripper design tab

4.4.7 Scenario Viewer – to View Report

After the ‘Design Air Stripper’ is clicked, the program develops a report with the optimal air stripper design, cost estimate, and predicted removals for the contaminants to be treated. One can use the ‘Scenario Viewer’ menu to view flowcharts, tables and various other information generated by the program. A complete explanation of the output report generation can be viewed in Section 4.4.10.

4.4.8 Edit Scenario – to Edit an Existing Scenario for Another Run

In the case of any corrections or changes to be made in design conditions, the ASDC program comes with an option to edit the entered data.

4.4.8.1 Edit Contaminant Entered

The program permits the user to edit, delete and reset compounds to the existing list of contaminants. For this, the user selects the ‘Edit Scenario’ function under the Contaminant tab in the main menu screen.

Contaminant Name	Contaminant Formula	Molecular Weight (g/mol)	Boiling Point
Acenaphthene	C12H10	154.2100000000	279.6
Acenaphthylene	C12H8	152.2000000000	280.1
Acetone	C3H6O	58.0900000000	56.1
Acrolein	C3H4O	56.0600000000	52.1
Acrylonitrile	C3H3N	53.0600000000	77.1

Scenario Name	Packing Name	Flow Rate (gpm)	Water Temperat...	Ambient Pr
Scenario 1	Tellerette #3 Ty...	100.00	25.00	

Scenario Name	Contaminant ID	Contaminant Name	Inlet ppb	Desired ppb
Scenario 1	1	Acenaphthene	100.00	
Scenario 1	2	Acenaphthylene	100.00	
Scenario 1	3	Acetone	100.00	

Figure 4-24. Screenshot of contaminant – edit scenario tab

To enter a new contaminant, click on the ‘New Contaminant’ tab under the properties – contaminant tab. The compound name and values for its properties are to be entered in the space provided; use the ‘Save’ function to add the new contaminant to the database of the existing list of contaminants. New compounds added will be sorted alphabetically, according to the first capital letter in the compound name.

Contaminant Name	Contaminant Formula	Molecular Weight (g/mol)
Acenaphthene	C12H10	154.21
Acenaphthylene	C12H8	152.20
Acetone	C3H6O	58.09
Acrolein	C3H4O	56.06
Acrylonitrile	C3H3N	53.06
Aldrin	C12H8Cl6	364.1
Aniline	C6H7N	93.09
Anthracene	C14H10	178.09
Benzene	C6H6	78.11
Benzidine	C12H12N2	184.1
Benzo[a] Anthracene	C18H12	228.29

Figure 4-25. Screenshot of contaminant – edit – new contaminant tab

To edit the compound properties, click on the “Existing Contaminant” tab and select the compound that needs to be edited using the dropdown menu. This will display the existing properties of the selected compound. Next, edit the required properties and click on ‘Save Edits’ to save changes made to the existing contaminant. Select ‘Clear/Refresh’ to clear any unsaved changes to the compound.

To delete a compound from the database, click on the existing contaminant tab and select the contaminant from the dropdown menu list and click ‘Delete’ to remove the contaminant from the database.

Contaminant Name	Contaminant Formula	Molecular Weight (g)
Acenaphthene	C12H10	154
Acenaphthylene	C12H8	152
Acetone	C3H6O	58
Acrolein	C3H4O	56
Aziridine	C3H3N	53
Aldrin	C12H8Cl6	364
Aniline	C6H7N	93
Anthracene	C14H10	178
Benzene	C6H6	78
Benadine	C12H12N2	184
Benzo[a] Anthracene	C18H12	228
Benzo[a] Pyrene	C20H12	252

Figure 4-26. Screenshot of contaminant – edit – existing contaminant tab

Properties relevant to prediction of air-water exchange have been compiled in a database for each of the compounds in the menu. The table in the top right-hand corner of the ASDC for Windows screen lists the properties included in the database. The property values for individual compounds are presented in the table for each compound. Most of the properties are for use in the Onda correlation for prediction of mass transfer coefficients. The Antoine constants, critical temperature and critical pressure are used to estimate the variation of the Henry’s Law equilibrium constant with temperature. Some additional properties relevant to the environmental fate and transport of the compound are also included for the user’s information.

Contaminant Name	Contaminant Formula	Molecular Weight (g/mol)	Boiling Point (°C)	Melting Point (°C)	Molar Volume (cm ³ /mol)	Vap
< Please Select a Scenario >	C12H10	154.2100000000	279.0000000000	96.2000000000	150.6000000000	
Acenaphthylene	C12H8	152.2000000000	280.0000000000	92.5000000000	169.4900000000	
Acetone	C3H6O	58.0900000000	56.2000000000	-95.3500000000	73.5000000000	
Acrolein	C3H4O	56.0600000000	52.5000000000	-87.7000000000	66.7000000000	
Acrylonitrile	C3H3N	53.0600000000	77.3000000000	-82.0000000000	65.8000000000	
Aldrin	C12H8Cl6	364.9200000000	145.0000000000	104.0000000000	214.6600000000	
Aniline	C6H7N	93.1200000000	184.0000000000	-6.3000000000	91.2000000000	
Anthracene	C14H10	178.2400000000	339.9000000000	216.3000000000	143.7400000000	
Benzene	C6H6	78.1100000000	80.1000000000	5.5000000000	88.9000000000	
Benzdine	C12H12N2	184.2300000000	401.7000000000	128.0000000000	147.3800000000	
Benzo[a] Anthracene	C18H12	228.3000000000	437.6000000000	162.0000000000	179.2000000000	
Benzo[a] Pyrene	C20H12	252.3200000000	495.0000000000	179.0000000000	186.7600000000	
Benzo[b] Fluoranthene	C20H12	252.3200000000	0.0000000000	168.0000000000	298.5000000000	
Benzo[ghi] perylene	C22H12	276.3400000000	500.0000000000	276.0000000000	280.0000000000	
Benzo[k] Fluoranthene	C20H12	252.3200000000	480.0000000000	217.0000000000	298.0000000000	
Benzoic Acid	C7H6O2	121.1200000000	249.2000000000	122.4000000000	112.6000000000	
Benzyl Butyl Phthalate	C19H20O4	312.3700000000	370.0000000000	-35.0000000000	278.9000000000	
Bis-(2-chloroethoxy) metha...	C9H10Cl2O2	173.9400000000	218.1000000000	-32.8000000000	140.2400000000	
Bis-(2-chloroethyl) Ether	C6H8Cl2O	143.0200000000	178.0000000000	-24.5000000000	117.2000000000	
Bis-(2-chloroisopropyl) Ether	C8H12Cl2O	171.0700000000	187.0000000000	96.8000000000	159.4000000000	
Bis-(2-ethylhexyl) Phthalate	C24H38O4	390.5700000000	384.1500000000	-45.8500000000	396.1000000000	
4-Bromophenyl Phenyl Ether	C12H9BrO	249.2000000000	305.1000000000	18.7000000000	154.8000000000	
2-Butanone	C4H8O	72.1100000000	79.6000000000	-85.9000000000	89.6000000000	
Carbon Disulfide	CS2	76.1300000000	46.5000000000	-111.5000000000	58.9000000000	

Figure 4-27. Screenshot of contaminant – edit – contaminant property tab

4.4.8.2 Edit Packing material

The user can add, edit or delete packing materials and their property values. To edit the packing material name and/or properties select the “Edit Scenario” tab under Packing and select a scenario from the drop-down option and click “Load”.

Packing Name	Nominal Size (mm)	Material	Surface Area (m ² /m ³)
Tellerette	25.40	Polypropylene	180.5
Tellerette #2 Ty...	50.80	Polypropylene	92.0
Tellerette #2 Ty...	50.80	Polypropylene	125.0
Tellerette #3 Ty...	76.20	Polypropylene	99.0
Intlox Snowflake	94.00	Plastic	91.8
Super Intalox Sa...	25.40	Ceramic	253.0
Super Intalox Sa...	50.80	Ceramic	105.0
Super Intalox Sa...	18.00	Plastic	207.0
Super Intalox Sa...	28.00	Plastic	108.0
Super Intalox Sa...	40.00	Plastic	89.0
Intalox Saddles 1...	25.40	Ceramic	256.0
Intalox Saddles 1...	38.10	Ceramic	195.0
Intalox Saddles 2...	50.80	Ceramic	118.0
Intalox Saddles 3...	76.20	Ceramic	89.0
Raschig Rings 1 L...	25.40	Ceramic	190.0
Raschig Rings 1 L...	38.10	Ceramic	125.0
Raschig Rings 2 L...	50.80	Ceramic	92.0
Raschig Rings 3 L...	75.00	Ceramic	62.0
Pall Rings 1 inch	25.40	Plastic	220.0
Pall Rings 1.5 inch	38.10	Plastic	138.0
Pall Rings 2 inch	50.80	Plastic	108.0
Pall Rings 3.5 inch	88.90	Plastic	85.0
Tri-Packs No. 1/2	25.40	Plastic	278.9

Figure 4-28. Screenshot of packing – edit – existing packing material

To input a new packing material, click on the ‘New Packing’ tab on the screen. The packing material name and values for its properties are typed in the spaces provided and use the ‘Save’ function to add the new packing material to the database of the existing list of packing materials. New packing materials added will be sorted alphabetically, according to the first capital letter in the packing material name.

To edit the packing material name and/or properties, click on the ‘Edit Packing’ tab on the screen and select the packing material to be edited from a drop down list of packing materials and click on ‘Load’ to display the existing properties of the packing material on the screen. Make the corrections on the existing properties as desired and press the ‘Save’ key to save the changes made to the packing material. The updated properties for the packing material will be displayed in the database on the right side of the screen. Select ‘Reset Fields’ to clear any unsaved changes to the existing packing material.

To delete a packing material from the database, click on the ‘Edit Packing’ tab and ‘Load’ the packing material from a drop-down menu list and click ‘Delete’ to remove the packing material from the database.

4.4.8.3 Edit Design Parameters

To edit the design parameters, click on the ‘Edit Scenario’ tab on the screen and select the packing material to be edited from a dropdown list of packing materials and click on ‘Load’ to display the existing properties of the packing material on the screen. Make the corrections on the existing properties as desired and press the ‘Save’ key to save the changes made to the packing material. The updated properties for the packing material will be displayed in the database on the right side of the screen. Select ‘Reset Fields’ to clear any unsaved changes to the existing packing material.

Scenario Name	Packing Name	Flow Rate (gpm)	Water Temperat.	Ambient
Scenario 1	Tellerette #3 Ty...	100.00	25.00	

Scenario Name	Contaminant ID	Contaminant Name	Inlet ppb	Desired c
Scenario 1	1	Acenaphthene	100.0000000000	10.00
Scenario 1	2	Acenaphthylene	100.0000000000	10.00
Scenario 1	3	Acetone	100.0000000000	10.00

Figure 4-29. Screenshot of design parameter – edit scenario tab

The ASDC for Windows program also provides an option for the user to override the program's choice of design contaminant. Select the 'Main Contaminant' tab under 'Design Parameter' and after 'Loading' the design scenario select the desired design contaminant from a dropdown list of the contaminants specified in the scenario and click 'Edit' to save the desired contaminant as the design contaminant.

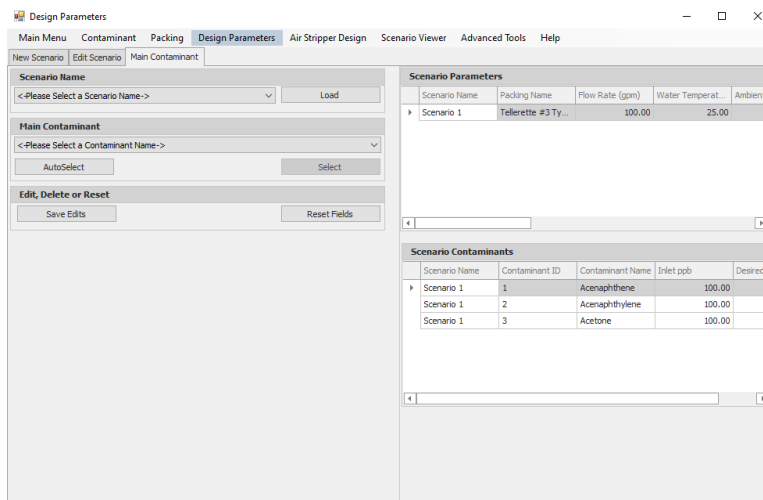


Figure 4-30. Screenshot of design parameter – main contaminant tab

4.4.9 Quick Start

The Quick Start menu is displayed to the right of the ASDC for Windows home screen which allows the user to execute the program swiftly if the user is familiar with the functions of the software.

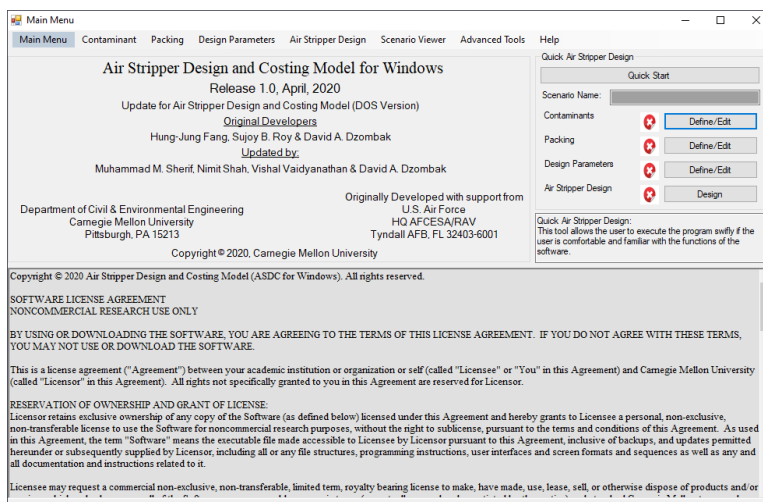


Figure 4-31. Screenshot of ASDC home screen – quick start

4.4.9.1 Scenario Selection

Once the Quick Start option is selected, a pop-up screen displays, asking for scenario name that needs to be entered by the user. The scenario name can consist of letters, numbers and special characters. After entering the scenario name, press the proceed button for contamination selection.

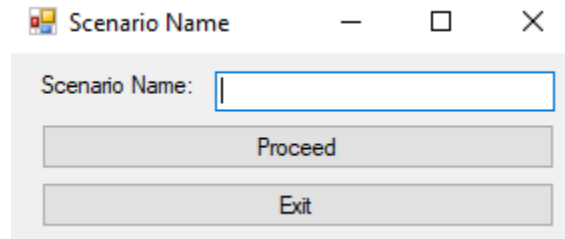


Figure 4-32. Screenshot of quick start – scenario name

4.4.9.2 Contaminant Selection

The next step of the Quick Start is selecting the contaminant(s) for which the air stripper is to be designed. A pop-up screen displays fields for selecting the contaminant using the dropdown menu.

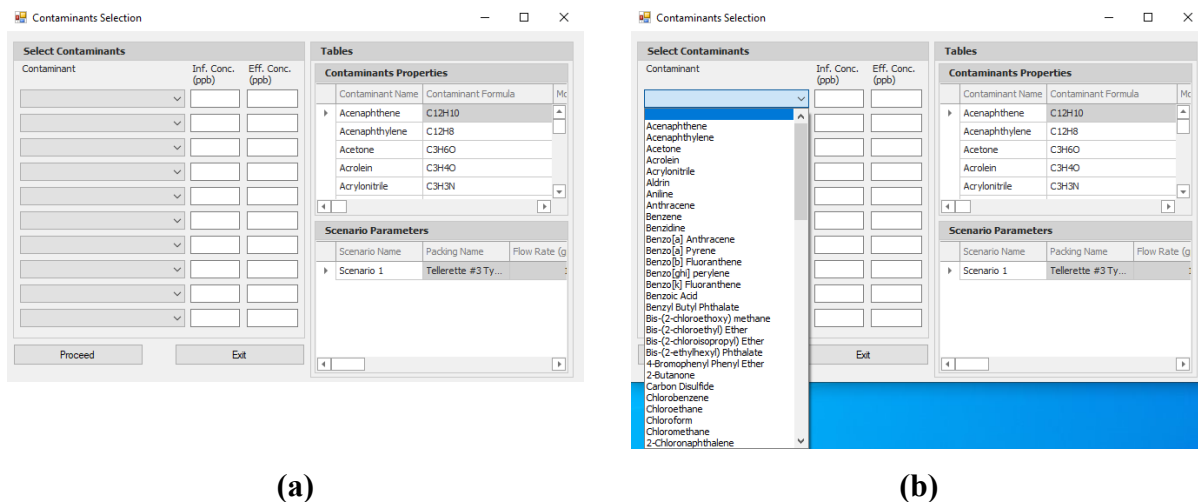


Figure 4-33. Screenshot of quick start – contaminant selection (a) before selection of contaminants and (b) after selection of contaminants

The influent concentration of the contaminant to be treated is to be given in parts per billion (ppb) units and the desired effluent concentration is to be entered as well.

Contaminant	Inf. Conc. (ppb)	Eff. Conc. (ppb)
Acenaphthene		
Acenaphthylene		

Contaminant Name	Contaminant Formula	Mc
Acenaphthene	C12H10	
Acenaphthylene	C12H8	
Acetone	C3H6O	
Acrolein	C3H4O	
Acrylonitrile	C3H3N	

Scenario Name	Packing Name	Flow Rate (g)
Scenario 1	Tellerette #3 Ty...	

Figure 4-34. Screenshot of quick start – contaminant influent and effluent concentration
Press the ‘Proceed’ button to continue to the next step.

4.4.9.3 Packing Material Selection

The next step in the process is selecting the packing material from the given list using the drop-down button.

Press the ‘Proceed’ button after selecting the packing material from the list shown above to continue to the design parameters.

Figure 4-35. Screenshot of quick start – packing material selection

4.4.9.4 Design parameters

After selecting the packing material, the program now asks for the design parameters for which the design cost will be estimated. Values such as flow rate, water temperature, ambient pressure, safety factor are to be entered by the user.

Design Parameters

Flow Rate gpm

Water Temperature °C

Ambient Pressure atm

Safety Factor KLa

Stripping Factor to by

ΔP (N/m²m) to by

Design Contaminant

Figure 4-36. Screenshot of quick start – design parameters

The ranges for stripping factor and pressure drop need to be provided along with the value by which the values are to be incremented.

After entering the characteristic design parameters, press the ‘Auto-Select’ button for the program to select the most appropriate contaminant to be treated. This auto-selection is performed by the software based on NTU and stripping factor explained in Section 2.2.

4.4.9.5 Report Generation

Once we click the proceed button, a report is generated having the details of the contaminant to be removed along with design parameters and cost estimates. A complete explanation of the output report generation can be viewed in Section 4.4.10.

4.4.10 Output and Report Options

The output generated using either the Standard Sequential Execution or Quick Start will give same report. However, using standard sequential execution process includes much more than the report such as a flowchart, table and so on using the tab ‘Scenario Viewer’.

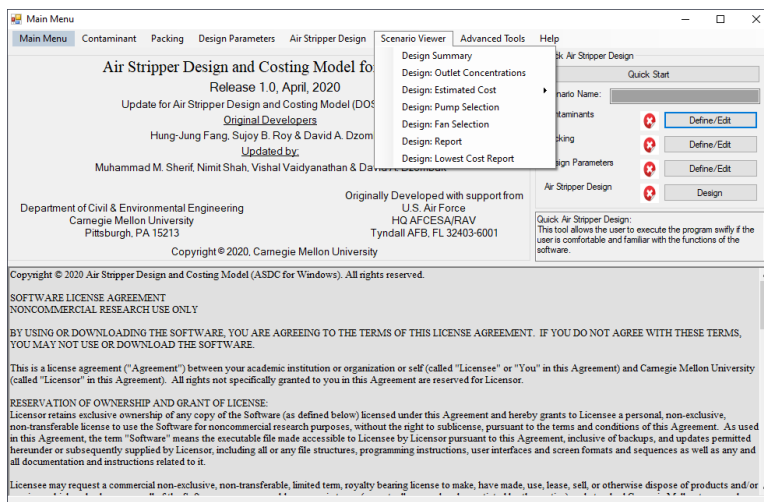


Figure 4-37. Screenshot of home screen – scenario viewer

The figure above shows the different options that can be generated and analyzed from the program. The design summary would generate a spreadsheet containing the design tower output, i.e. tower height, column height and the diameter for different stripping factors and pressure drop as shown in figure 4-42.

	A	B	C	D	E	F	G
1	Design Tower Output						
2	Delta P (N/m ² .m)	SF: 40 (T.H.)	SF: 40 (C.H.)	SF: 40 (d)	SF: 50 (T.H.)	SF: 50 (C.H.)	SF: 50 (d)
3	50	2.07	1.59	0.61	1.97	1.51	0.68
4	55	2.09	1.61	0.6	1.99	1.53	0.66
5	60	2.11	1.62	0.59	2	1.54	0.65
6	65	2.13	1.64	0.58	2.02	1.55	0.64
7	70	2.14	1.65	0.57	2.03	1.56	0.63
8	75	2.16	1.66	0.56	2.05	1.58	0.62
9	80	2.17	1.67	0.55	2.06	1.58	0.61

Figure 4-38. Screenshot of design summary excel sheet

The design outlet concentrations options would generate the effluent output concentration that is achieved by the design and the packing material entered.

The estimated cost option provides the user with a cost tree or charts as shown below. Two different types of charts can be generated, namely: Line Plot and Pie chart.

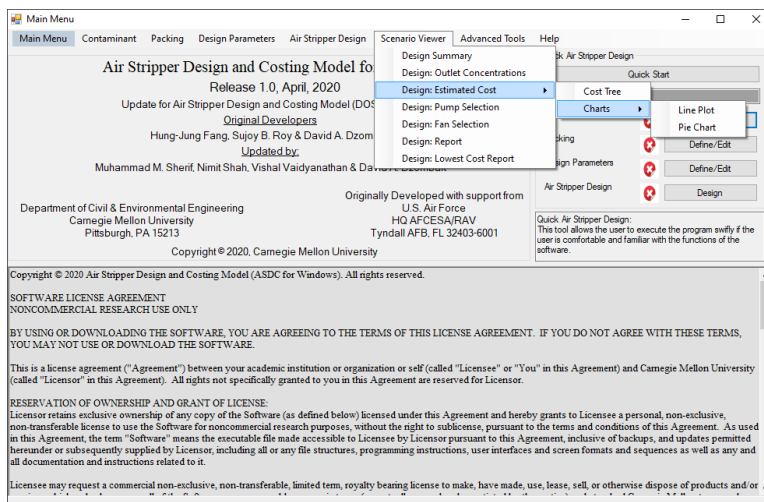


Figure 4-39. Screenshot of design estimated cost display options

The line plot can be plotted either between cost and stripping factor, keeping a constant pressure drop or between cost and pressure drop at a constant stripping factor. The figure below shows a line plot plotted between cost and stripping factor at a pressure drop of 60.

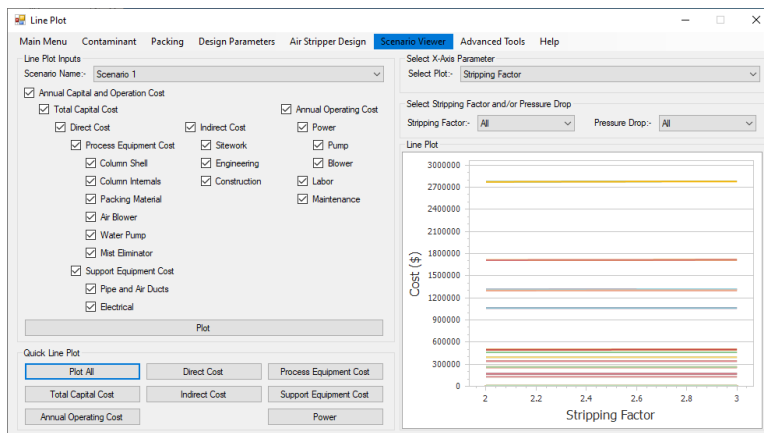


Figure 4-40. Screenshot of line plot

Using a pointer by dragging over the different stripping factor values, the program displays the cost at the particular stripping factor and given pressure drop as shown below. This can be used to observe which stripping factor and pressure drop would give the least expensive design cost for the required air stripper.

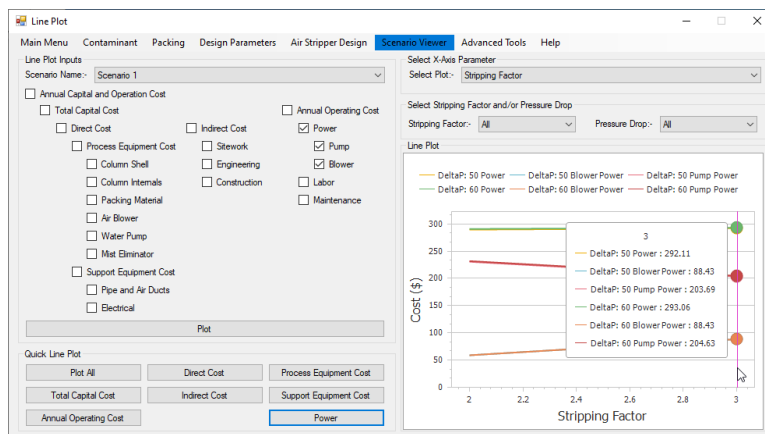


Figure 4-41. Screenshot of line plot – interpretation

The pie chart requires the user to specify a particular stripping factor and pressure drop unlike the line plot. The pie chart shows the distribution of cost in terms of percentages as shown below.

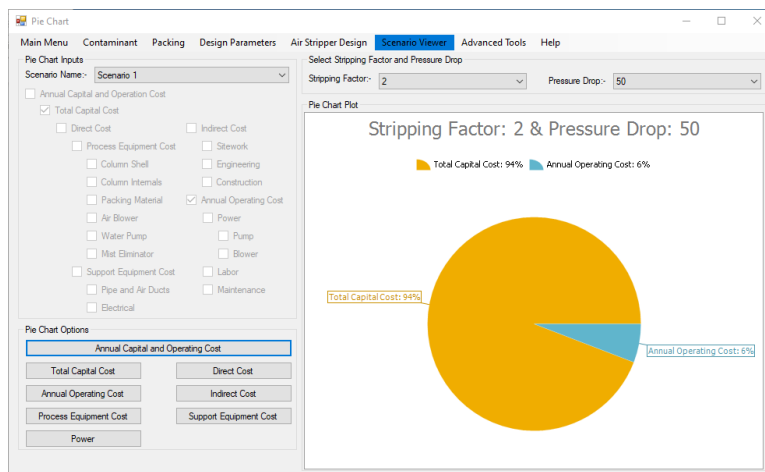


Figure 4-42. Screenshot of pie chart

The “Design: Report” generates the report with the every possible detail obtained and calculated from the user specifications. The report includes the scenario name, the date on which the report was generated, the contaminant list, contaminant concentrations, the packing materials, the design parameters such as Henry’s Law constant, vapor pressure and the cost for the air stripper to be designed.

Figures 4-43 to 4-46 present the screenshots of the report generated by the program for an example case: two contaminants, Acenaphthene and Benzene, with the packing material Tellerette #2 type K. The report consists of four pages.

The first page of the report contains all the basic design parameters and the contaminant properties as well. Here, only the property of benzene is displayed since out of the two selected contaminants, benzene is more volatile and based on the principle described in Section 2.2 it was selected as the design contaminant.

The second page of the report contains the packing material details along with mass transfer and physical properties of water displayed. The third and the fourth pages of the report contain quantitative information of the contaminant to be removed and the cost estimates for the given case, respectively.

Every page of the report contains a header displaying the stripping factor and the pressure drop for which the report is generated and a footer containing information such as the scenario name, page number and the date on which the report was generated.

The “Design: Final Report” generates a report for the design with the estimated lowest overall cost. This can be used as the optimum design for the entered conditions by the user to find the system that achieves the design objectives at minimum cost.

ASDC Design Summary

Stripping Factor : 2.000

ΔP : 45.000 (N/m² m)

System Design Parameters

Water Temperature : 25.000 (°C)

Water Flow Rate : 100.000 (gpm)

Ambient Pressure : 1.000 (atm)

Tower Diameter : 1.91 (m)

Packing Height : 4.83 (m)

Tower Height : 3.71 (m)

Volumetric Air/Water Ratio : 326.2

Water Mass Loading Rate : 2.201E+00 (kg/m²/sec)

Air Mass Loading Rate : 8.529E-01 (kg/m²/sec)

Air Flow Rate : 4360.23 (cfm)

Design Contaminant Properties

Name : Acenaphthene

Formula : C₁₂H₁₀

Molecular Weight : 154.210 (g/mol)

Boiling Point : 279.000 (°C)

Molar Volume : 150.600 (cm³/mol)

Vapor Pressure @ 25.00 °C : 1.550E-03 (mmHg)

Solubility @ 25.00 °C : 3.930E+00 (mg/L)

Henry's Constant @ 25.00 °C : 1.500E-04 (atm.m³/mol)

Henry's Constant @ 25.00 °C : 1.500E-04 (atm.m³/mol)

Diffusivity in Air : 6.861E-02 (cm²/sec)

Diffusivity in Water : 7.893E-06 (cm²/sec)

ASDC Design Scenario : Trial 1

Stripping Factor : 2.000

ΔP : 45.000 (N/m² m)

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Figure 4-43. Sample of ASDC Design Summer Report Page 1

ASDC Design Summary

Stripping Factor : 2.000

ΔP : 45.000 (N/m² m)

Packing Material Properties

Name : Tellerette

Material : Polypropylene

Nominal Size : 25.400 (mm)

Specific Area : 180.500 (m²/m³)

Packing Factor : 40.000 (1/ft)

Mass Transfer Parameters

Packing Material Wetted Area : 52.696 (m²/m³)

Mass Transfer Rate in Water : 7.474E-05 (m/sec)

Mass Transfer Rate in Air : 1.969E-02 (m/sec)

Overall Mass Transfer Rate : 2.841E-06 (m/sec)

Overall Mass Transfer Coefficient : 2.027E-03 (1/sec)

Overall KLa Safety Factor : 1.2

Height of Transfer Unit (HTU) : 1.089 (m)

Physical Properties of Water/Air

Density of Water : 9.970E+02 (kg/m³)

Viscosity of Water : 8.905E-01 (Centipose)

Surface Tension of Water : 7.195E-02 (Kg/Sec²)

Density of Air : 1.184E+00 (g/L)

Viscosity of Air : 1.835E-05 (Nüsec/m²)

ASDC Design Scenario : Trial 1

Stripping Factor : 2.000

ΔP : 45.000 (N/m² m)

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Figure 4-44. Sample of ASDC Design Summer Report Page 2

ASDC Design Summary

Stripping Factor : 2.000

ΔP : 45.000 (N/m² m)

Contaminant Removal

Contaminant Name	Influent Conc ppb	Desired Conc ppb	Effluent Conc ppb	Efficiency %
Acenaphthene	100	10	10	90
Acenaphthylene	100	10	3.96	96.04

Cost Parameters

Labor Rate : 0.005 (\$/1000Gal)

Electric Rate : 0.08 (\$/kWh)

ENR Index (Year : 2019) : 11281

Operating Hours per Day : 24 (Hr/Day)

Operating Days per Year : 365 (Day/Year)

Interest Rate : 10 (%)

Authorization Period : 20 (Year)

Figure 4-45. Sample of ASDC Design Summer Report Page 3

ASDC Design Summary

Stripping Factor : 2.000

$\Delta P : 45.000 \text{ (N/m}^2 \text{ m)}$

Cost Estimate

Capital Cost

Column Shell : \$19349

Column Internals : \$8747

Packing Material : \$21862

Air Blower : \$6694

Water Pump : \$5995

Mist Eliminator : \$1750347

Process Equipment Cost : \$1812993

Pipe & Air Ducts : \$362711

Electrical : \$181299

Support Equipment Cost : \$547122

Total Direct Cost : \$2360116

Sitework : \$354017

Engineering : \$637231

Construction : \$472023

Total Indirect Cost : \$1463272

Total Capital Cost : \$3823388

Annual Cost (\$/Year)

Blower Operating Cost : \$1046

Pump Operating Cost : \$920

Labor Cost : \$263

Maintenance Cost : \$236012

Annual Operating Cost : \$238240

Amortized Capital Cost : \$449094

Total Annual Cost : \$687334

ASDC Design Scenario : Trial 1

Stripping Factor : 2.000

$\Delta P : 45.000 \text{ (N/m}^2 \text{ m)}$

Thursday, April 23, 2020

Page 4 of 4

Figure 4-46. Sample of ASDC Design Summer Report Page 4

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Appendix A: Water Pump Characteristic Curves

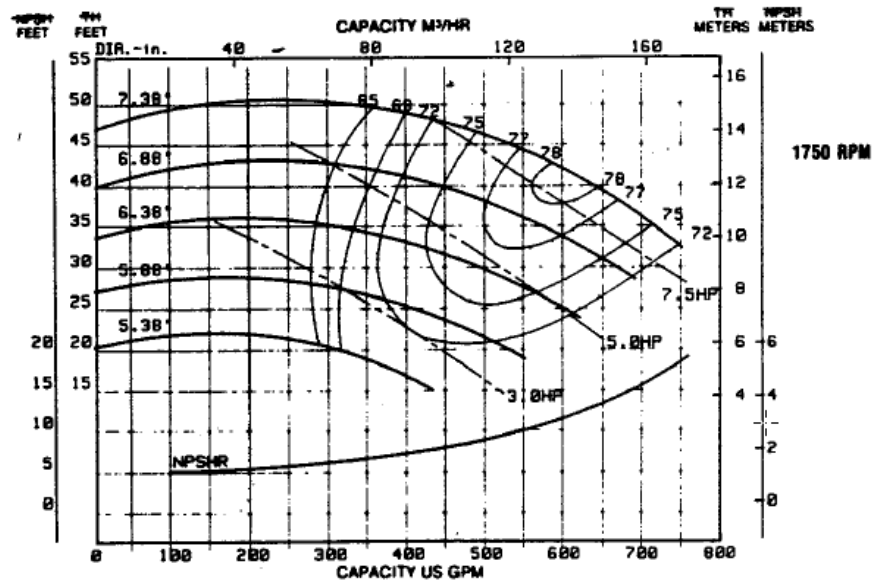


Figure A1. Type 1 pump characteristic curves

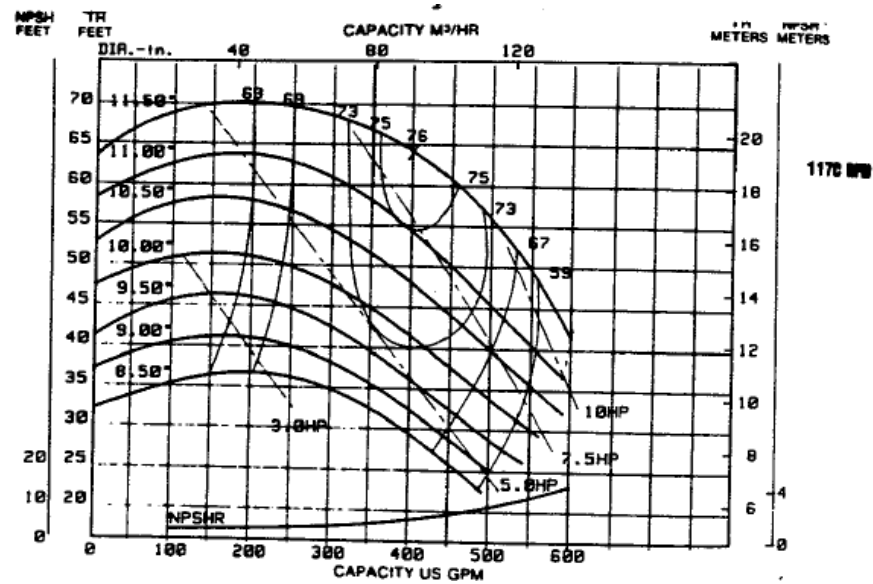


Figure A2. Type 2 pump characteristic curves

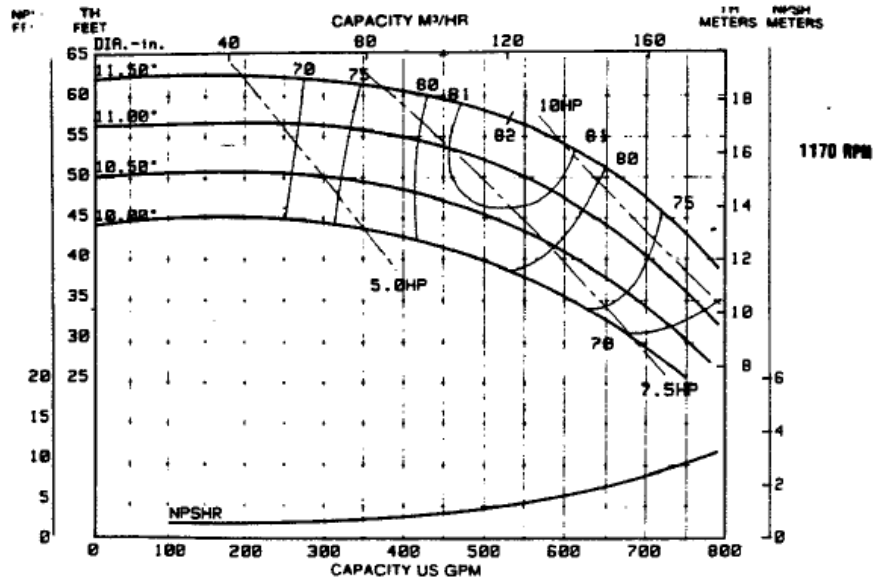


Figure A3. Type 3 pump characteristic curves

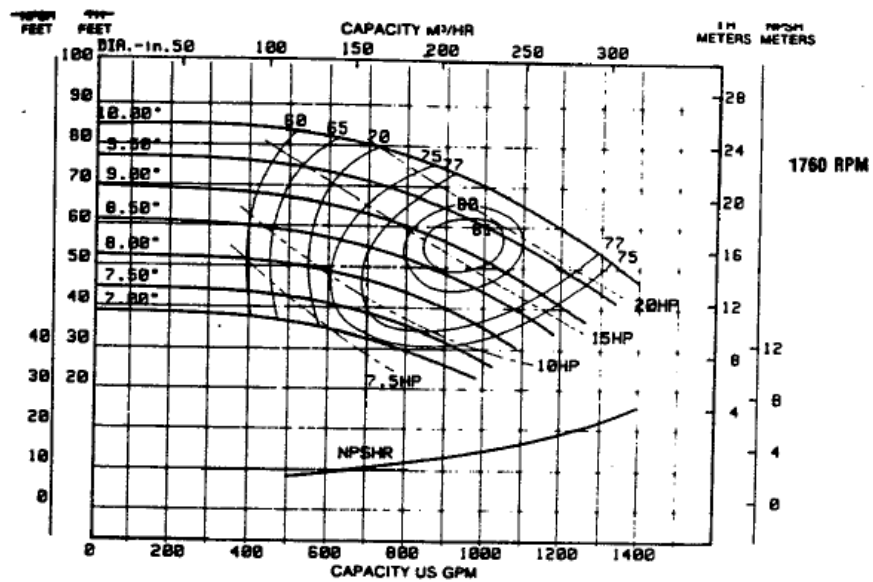


Figure A4. Type 4 pump characteristic curves

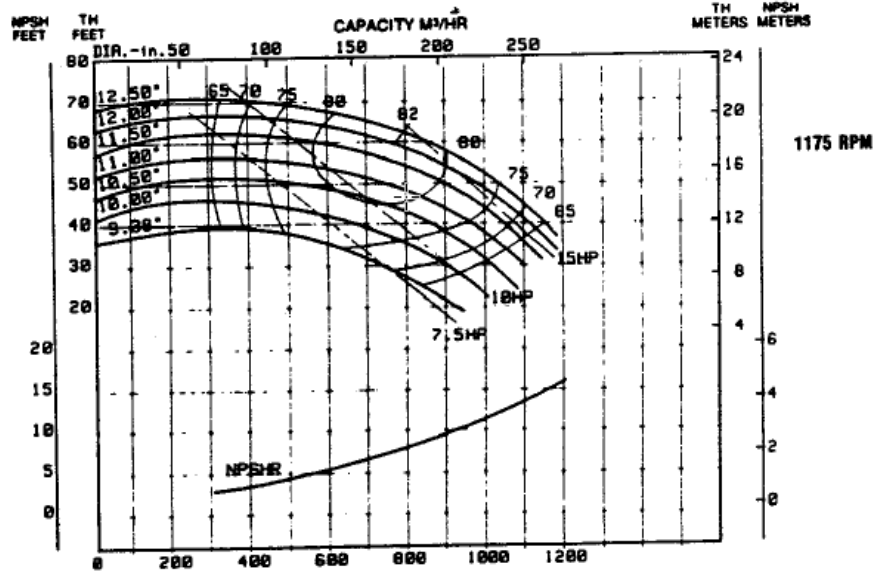


Figure A5. Type 5 pump characteristic curves

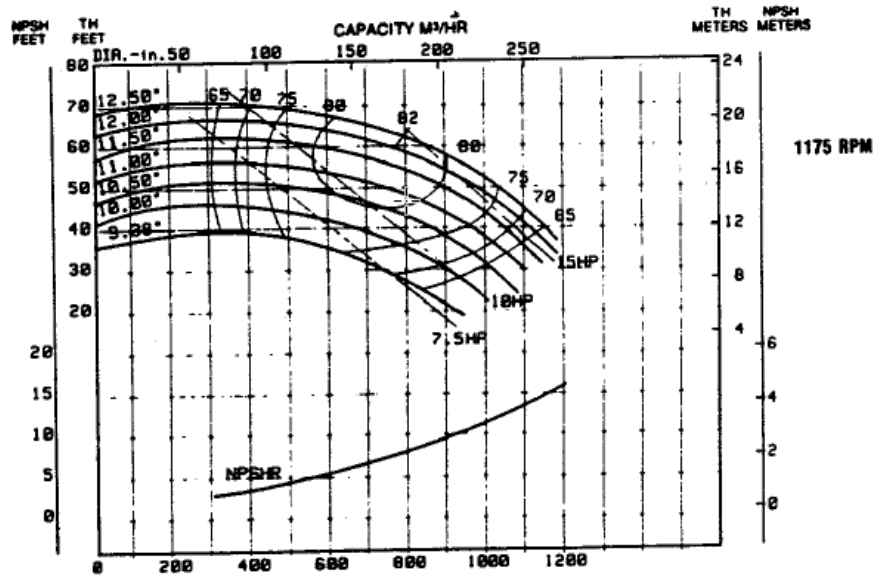


Figure A6. Type 6 pump characteristic curves

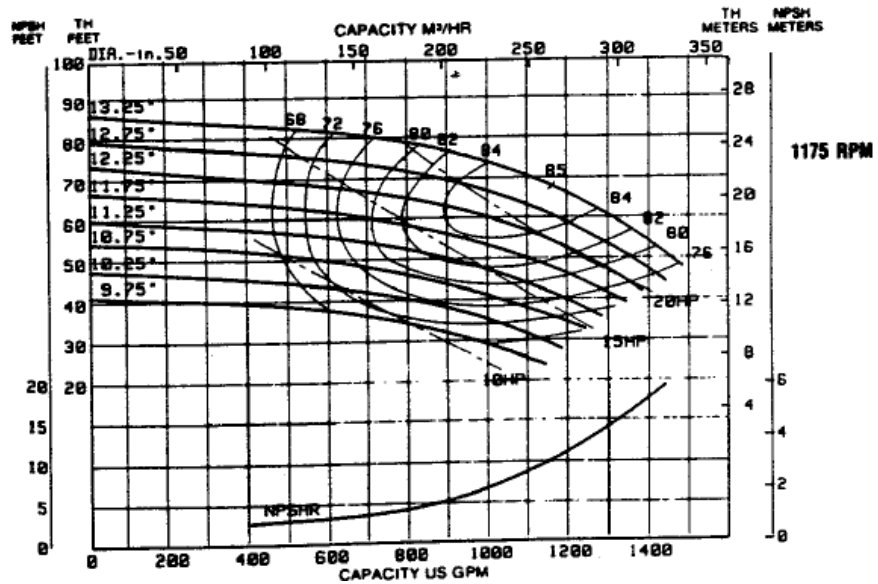


Figure A7. Type 7 pump characteristic curves

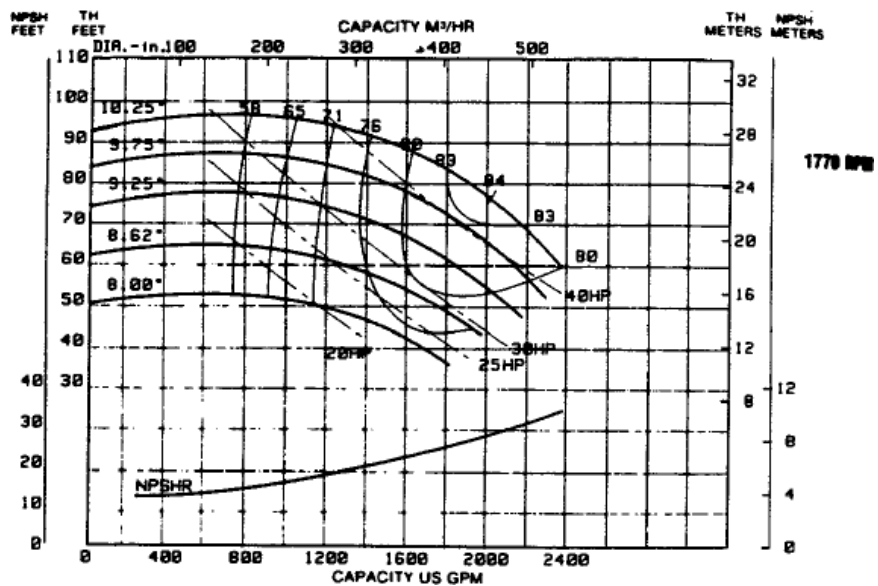


Figure A8. Type 8 pump characteristic curves

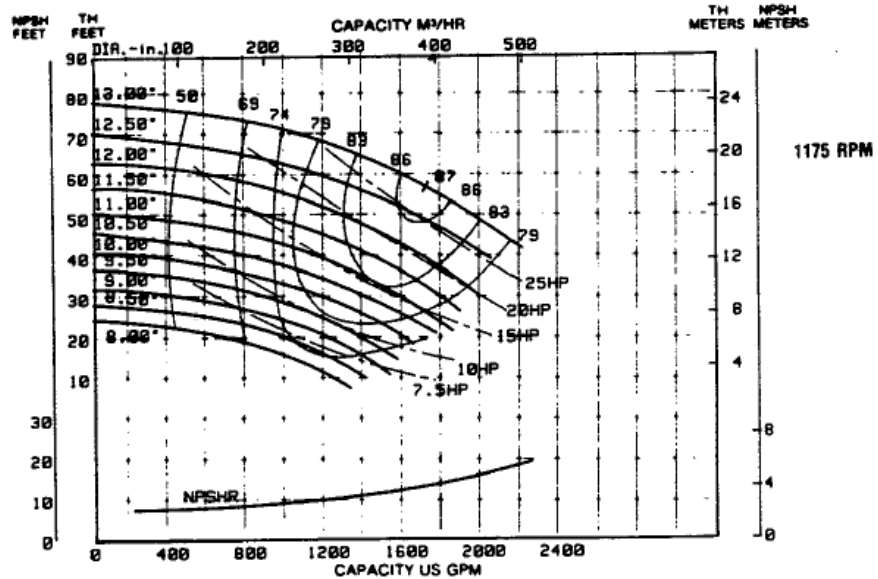


Figure A9. Type 9 pump characteristic curves

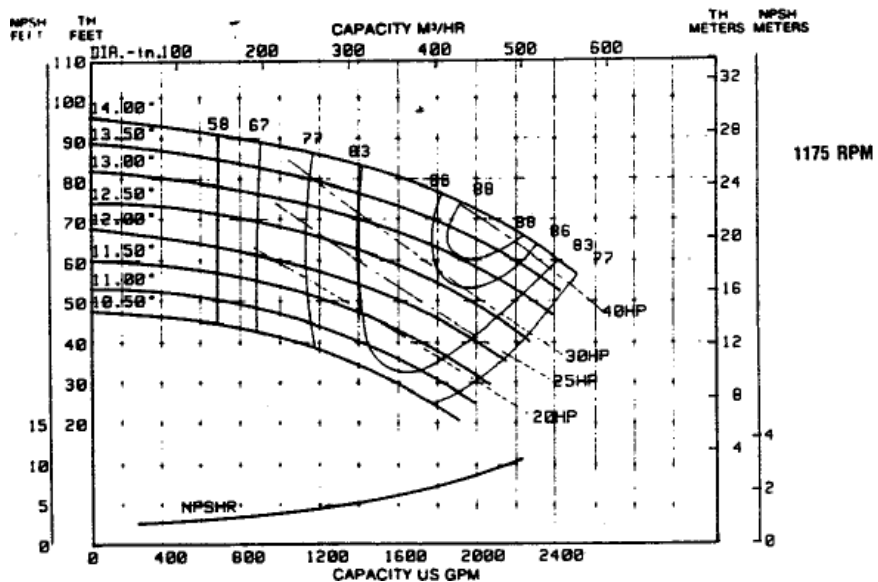


Figure A10. Type 10 pump characteristic curves

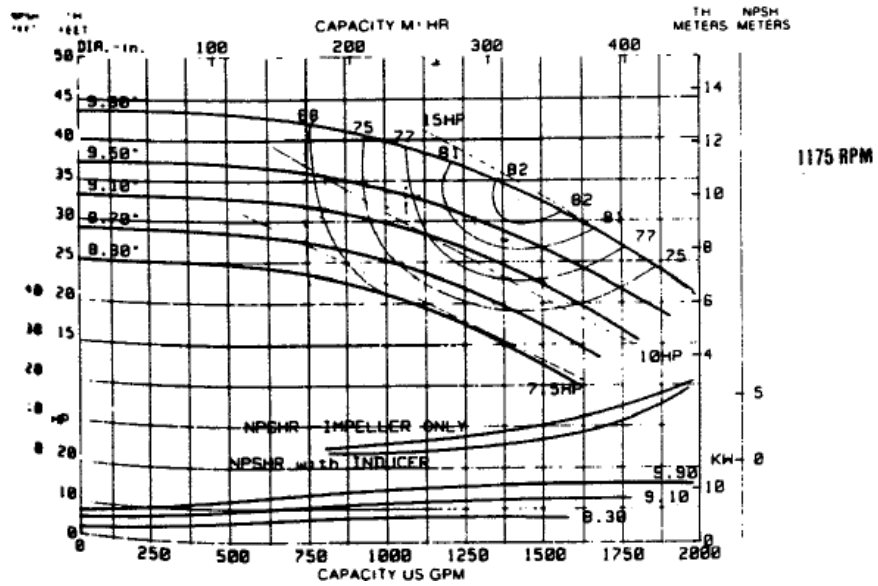


Figure A11. Type 11 pump characteristic curves

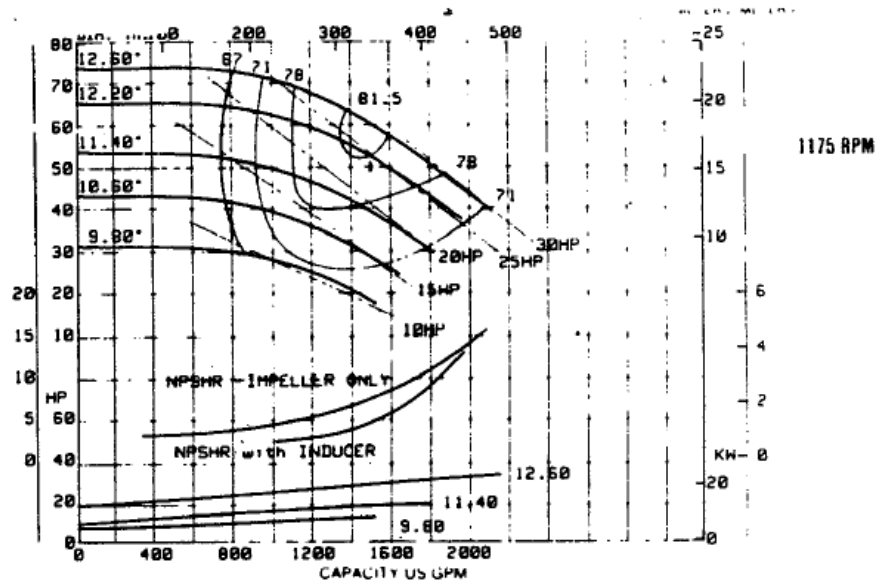


Figure A12. Type 12 pump characteristic curves

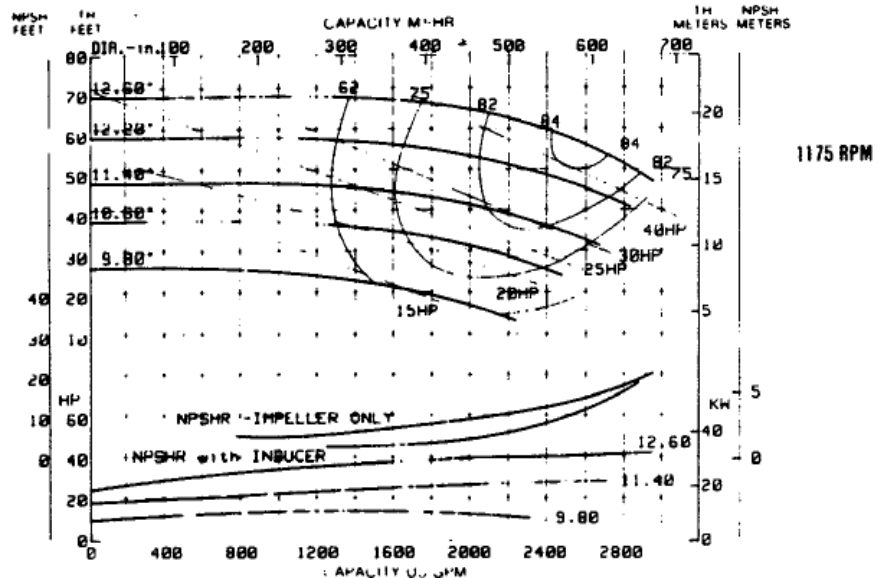


Figure A13. Type 13 pump characteristic curves

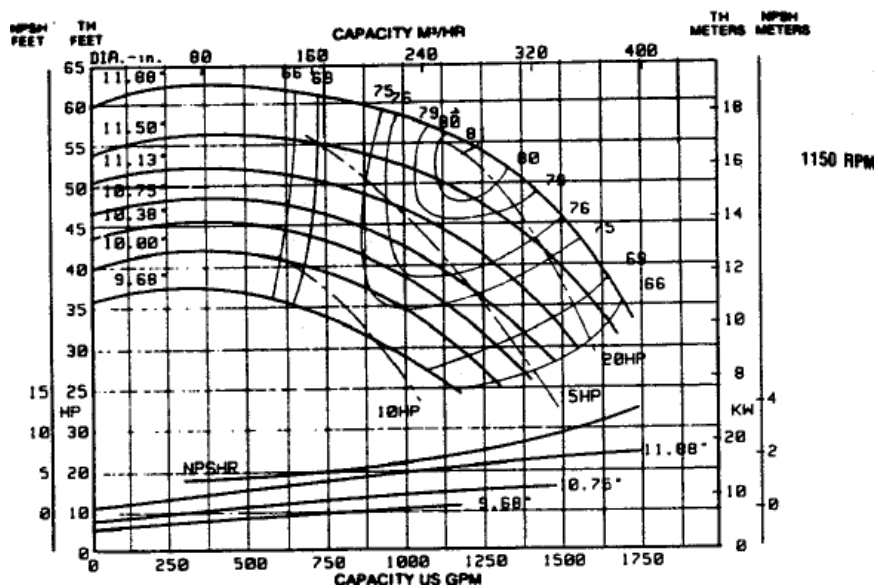


Figure A14. Type 14 pump characteristic curves

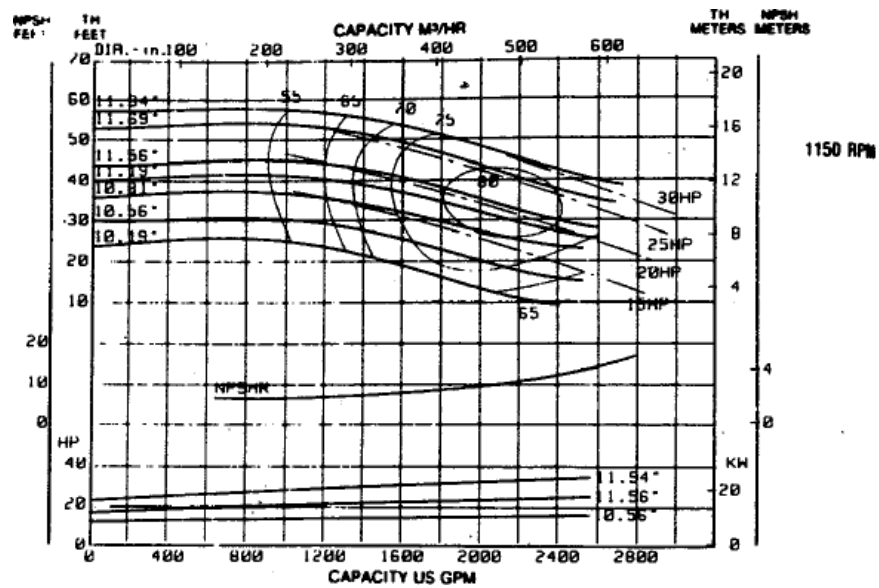


Figure A15. Type 15 pump characteristic curves

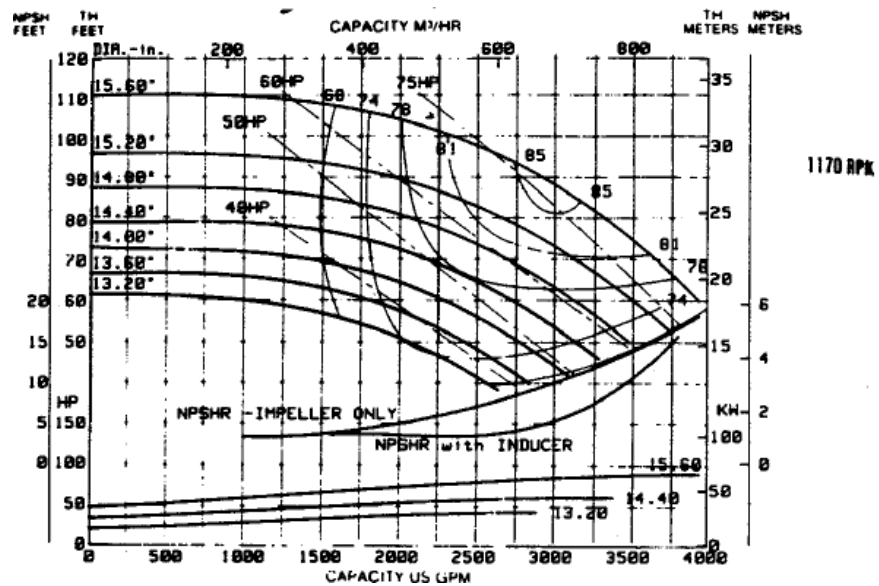


Figure A16. Type 16 pump characteristic curves

Appendix B: Fan Capacity Tables

Table B1. Type 1 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
200	0.04	0.07	0.11	0.15	0.19	0.23	0.28	0.33	0.38	0.43	0.49	0.54	0.60	0.65	0.71	0.78	0.91	1.04
250	0.05	0.09	0.13	0.18	0.22	0.27	0.32	0.38	0.43	0.49	0.55	0.61	0.67	0.74	0.80	0.87	1.00	1.14
300	0.07	0.11	0.16	0.21	0.26	0.32	0.37	0.43	0.49	0.55	0.62	0.68	0.75	0.82	0.89	0.96	1.11	1.26
350	0.10	0.14	0.20	0.25	0.31	0.37	0.43	0.49	0.56	0.62	0.69	0.76	0.83	0.91	0.98	1.06	1.22	1.38
400	0.13	0.18	0.24	0.30	0.36	0.42	0.49	0.56	0.63	0.7	0.77	0.85	0.92	1.00	1.08	1.16	1.33	1.50
450	0.16	0.22	0.29	0.35	0.42	0.49	0.56	0.63	0.71	0.79	0.86	0.94	1.03	1.11	1.19	1.27	1.44	1.63
500	0.21	0.28	0.34	0.42	0.49	0.56	0.64	0.72	0.80	0.88	0.96	1.05	1.13	1.22	1.31	1.40	1.58	1.77
550	0.26	0.34	0.41	0.49	0.57	0.65	0.73	0.81	0.90	0.98	1.07	1.16	1.25	1.35	1.44	1.53	1.73	1.93
600	0.33	0.41	0.49	0.57	0.65	0.74	0.83	0.92	1.01	1.10	1.19	1.28	1.38	1.48	1.58	1.68	1.89	2.10
650	0.40	0.49	0.58	0.66	0.75	0.84	0.94	1.03	1.13	1.23	1.32	1.42	1.52	1.62	1.73	1.84	2.05	2.27
700	0.49	0.58	0.67	0.77	0.86	0.95	1.06	1.16	1.26	1.36	1.47	1.57	1.68	1.79	1.89	2.00	2.23	2.46
750	0.59	0.69	0.79	0.89	0.98	1.08	1.19	1.29	1.40	1.51	1.62	1.73	1.85	1.96	2.07	2.19	2.42	2.66
800	0.71	0.80	0.91	1.02	1.12	1.23	1.33	1.44	1.56	1.67	1.79	1.91	2.03	2.15	2.27	2.39	2.63	2.87
850	0.83	0.94	1.05	1.16	1.27	1.39	1.50	1.61	1.73	1.85	1.97	2.10	2.22	2.34	2.47	2.60	2.86	3.11
900	0.98	1.08	1.20	1.32	1.44	1.56	1.68	1.79	1.91	2.04	2.17	2.30	2.43	2.56	2.69	2.82	3.09	3.37
950	1.13	1.25	1.37	1.50	1.62	1.75	1.87	2.00	2.12	2.24	2.38	2.52	2.65	2.79	2.93	3.07	3.34	3.63
1000	1.31	1.43	1.55	1.69	1.82	1.95	2.09	2.22	2.35	2.48	2.61	2.75	2.89	3.04	3.18	3.33	3.62	3.91
1050	1.50	1.63	1.76	1.89	2.03	2.17	2.31	2.45	2.59	2.73	2.86	3.00	3.14	3.30	3.45	3.60	3.91	4.21
1100	1.72	1.85	1.98	2.12	2.27	2.42	2.56	2.71	2.85	3.00	3.14	3.28	3.42	3.57	3.73	3.89	4.21	4.53
1150	1.95	2.09	2.23	2.36	2.52	2.67	2.83	2.98	3.13	3.28	3.43	3.58	3.73	3.88	4.03	4.20	4.53	4.86
1200	2.20	2.35	2.49	2.63	2.79	2.95	3.11	3.27	3.43	3.59	3.75	3.90	4.06	4.22	4.37	4.53	4.87	5.22
1250	2.47	2.63	2.78	2.93	3.08	3.25	3.42	3.59	3.75	3.92	4.08	4.25	4.41	4.57	4.73	4.90	5.23	5.59
1300	2.77	2.93	3.09	3.24	3.40	3.57	3.75	3.92	4.09	4.27	4.44	4.61	4.78	4.95	5.12	5.29	5.63	5.98
1350	3.08	3.25	3.42	3.58	3.74	3.91	4.10	4.28	4.46	4.64	4.82	4.99	5.17	5.35	5.53	5.71	6.05	6.40
1400	3.43	3.60	3.77	3.94	4.11	4.28	4.47	4.66	4.84	5.03	5.22	5.40	5.59	5.77	5.96	6.14	6.51	6.87

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B2. Type 2 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
500	0.11	0.19	0.26	0.35	0.44	0.53	0.62	0.73	0.83	0.94	1.05	1.17	1.28	1.40	1.52	1.65	1.90	2.16
600	0.16	0.24	0.33	0.43	0.53	0.63	0.73	0.84	0.95	1.07	1.19	1.32	1.44	1.58	1.71	1.84	2.12	2.40
700	0.22	0.31	0.41	0.52	0.63	0.74	0.86	0.98	1.10	1.23	1.35	1.48	1.62	1.75	1.90	2.04	2.34	2.65
800	0.29	0.40	0.51	0.63	0.75	0.87	0.99	1.13	1.26	1.40	1.54	1.68	1.82	1.97	2.11	2.26	2.57	2.90
900	0.39	0.50	0.62	0.75	0.88	1.02	1.16	1.29	1.44	1.59	1.74	1.89	2.04	2.20	2.36	2.52	2.85	3.18
1000	0.50	0.63	0.76	0.90	1.04	1.19	1.34	1.49	1.64	1.79	1.95	2.12	2.29	2.45	2.62	2.79	3.15	3.50
1100	0.63	0.78	0.92	1.07	1.22	1.38	1.54	1.70	1.87	2.03	2.20	2.37	2.54	2.73	2.91	3.09	3.46	3.84
1200	0.79	0.95	1.11	1.27	1.42	1.59	1.77	1.94	2.12	2.30	2.48	2.66	2.84	3.02	3.21	3.41	3.80	4.21
1300	0.98	1.15	1.32	1.49	1.66	1.83	2.02	2.21	2.40	2.58	2.78	2.97	3.17	3.36	3.56	3.76	4.16	4.59
1400	1.20	1.37	1.56	1.75	1.93	2.11	2.29	2.49	2.70	2.90	3.10	3.31	3.52	3.73	3.94	4.15	4.58	5.01
1500	1.45	1.63	1.83	2.03	2.23	2.43	2.62	2.81	3.03	3.25	3.47	3.68	3.90	4.12	4.35	4.57	5.03	5.48
1600	1.73	1.93	2.13	2.35	2.56	2.77	2.98	3.19	3.40	3.62	3.85	4.08	4.32	4.55	4.78	5.02	5.50	5.99
1700	2.05	2.26	2.47	2.70	2.92	3.15	3.38	3.60	3.82	4.04	4.27	4.52	4.77	5.01	5.26	5.51	6.00	6.51
1800	2.41	2.63	2.85	3.09	3.33	3.57	3.80	4.04	4.28	4.51	4.74	4.99	5.25	5.51	5.77	6.03	6.55	7.08
1900	2.81	3.04	3.27	3.51	3.77	4.02	4.28	4.52	4.78	5.03	5.27	5.51	5.76	6.04	6.31	6.59	7.14	7.69
2000	3.25	3.5	3.73	3.98	4.25	4.52	4.78	5.05	5.31	5.57	5.84	6.10	6.35	6.61	6.89	7.19	7.76	8.35
2100	3.74	3.99	4.25	4.50	4.78	5.06	5.34	5.62	5.90	6.17	6.45	6.72	7.00	7.27	7.54	7.82	8.43	9.04
2200	4.27	4.54	4.80	5.07	5.35	5.64	5.94	6.23	6.52	6.81	7.11	7.39	7.68	7.97	8.26	8.54	9.13	9.77
2300	4.85	5.13	5.41	5.69	5.96	6.27	6.58	6.89	7.20	7.50	7.81	8.11	8.41	8.71	9.01	9.32	9.91	10.54
2400	5.49	5.78	6.07	6.37	6.65	6.96	7.28	7.60	7.92	8.24	8.56	8.87	9.19	9.51	9.83	10.14	10.76	11.38
2500	6.17	6.48	6.79	7.09	7.39	7.69	8.03	8.37	8.70	9.03	9.37	9.69	10.02	10.36	10.69	11.01	11.67	12.32

Note: 1. S.P. (Static Pressure: in H₂O)
 2. BHP does not include drive losses

Table B3. Type 3 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
800	0.18	0.30	0.42	0.56	0.70	0.85	0.99	1.15	1.32	1.49	1.67	1.85	2.04	2.22	2.42	2.61	3.01	3.42
900	0.23	0.35	0.49	0.64	0.79	0.94	1.11	1.27	1.44	1.62	1.81	2.00	2.20	2.39	2.60	2.80	3.22	3.66
1000	0.28	0.42	0.57	0.72	0.88	1.05	1.22	1.40	1.58	1.77	1.95	2.15	2.36	2.57	2.78	3.00	3.45	3.90
1100	0.34	0.49	0.65	0.82	0.98	1.16	1.35	1.53	1.73	1.93	2.13	2.33	2.54	2.75	2.97	3.20	3.67	4.15
1200	0.42	0.57	0.75	0.92	1.10	1.29	1.48	1.68	1.89	2.09	2.31	2.52	2.74	2.96	3.19	3.41	3.90	4.40
1300	0.50	0.67	0.85	1.04	1.23	1.43	1.63	1.84	2.06	2.27	2.50	2.72	2.95	3.19	3.42	3.66	4.15	4.65
1400	0.60	0.78	0.97	1.17	1.37	1.58	1.80	2.01	2.23	2.46	2.70	2.94	3.17	3.42	3.67	3.92	4.43	4.95
1500	0.70	0.90	1.10	1.31	1.53	1.75	1.97	2.20	2.43	2.66	2.92	3.16	3.41	3.67	3.92	4.19	4.72	5.27
1600	0.82	1.04	1.25	1.46	1.69	1.92	2.16	2.40	2.65	2.89	3.13	3.40	3.67	3.93	4.20	4.47	5.03	5.60
1700	0.96	1.19	1.41	1.63	1.87	2.12	2.37	2.62	2.87	3.13	3.39	3.65	3.92	4.20	4.49	4.77	5.34	5.93
1800	1.11	1.35	1.59	1.82	2.06	2.32	2.59	2.84	3.12	3.39	3.66	3.93	4.21	4.49	4.78	5.08	5.69	6.29
1900	1.29	1.53	1.78	2.03	2.28	2.55	2.82	3.09	3.37	3.66	3.95	4.23	4.52	4.81	5.09	5.41	6.03	6.67
2000	1.47	1.73	2.00	2.26	2.52	2.78	3.07	3.36	3.65	3.94	4.24	4.55	4.85	5.15	5.45	5.75	6.39	7.05
2100	1.68	1.94	2.22	2.50	2.78	3.05	3.34	3.64	3.95	4.25	4.56	4.87	5.19	5.51	5.82	6.14	6.78	7.46
2200	1.91	2.17	2.47	2.76	3.05	3.34	3.62	3.94	4.26	4.57	4.89	5.22	5.54	5.87	6.21	6.54	7.21	7.87
2300	2.15	2.43	2.74	3.04	3.34	3.65	3.94	4.25	4.58	4.92	5.26	5.59	5.91	6.26	6.61	6.96	7.65	8.35
2400	2.42	2.71	3.02	3.34	3.66	3.98	4.29	4.60	4.93	5.28	5.63	5.98	6.32	6.67	7.03	7.39	8.11	8.84
2500	2.71	3.01	3.33	3.67	4.00	4.33	4.66	4.98	5.30	5.66	6.02	6.39	6.75	7.11	7.47	7.84	8.59	9.34
2600	3.02	3.33	3.66	4.01	4.36	4.70	5.04	5.38	5.72	6.06	6.44	6.82	7.19	7.57	7.94	8.32	9.09	9.88
2700	3.36	3.69	4.02	4.38	4.74	5.10	5.45	5.81	6.16	6.51	6.87	7.26	7.66	8.04	8.43	8.83	9.60	10.42
2800	3.72	4.06	4.39	4.77	5.14	5.52	5.89	6.26	6.62	6.99	7.34	7.73	8.14	8.54	8.95	9.35	10.16	10.99
2900	4.10	4.46	4.81	5.19	5.58	5.96	6.35	6.73	7.11	7.49	7.86	8.24	8.64	9.07	9.48	9.90	10.74	11.58
3000	4.52	4.89	5.25	5.63	6.04	6.43	6.83	7.23	7.62	8.02	8.40	8.79	9.18	9.60	10.05	10.47	11.35	12.21
3100	4.96	5.34	5.71	6.09	6.52	6.93	7.34	7.75	8.17	8.57	8.98	9.37	9.77	10.18	10.62	11.07	11.97	12.87
3200	5.43	5.82	6.21	6.59	7.02	7.46	7.88	8.30	8.72	9.15	9.57	9.99	10.4	10.82	11.22	11.68	12.62	13.54
3100	5.93	6.34	6.74	7.13	7.56	8.01	8.45	8.88	9.32	9.76	10.2	10.62	11.06	11.48	11.91	12.33	13.30	14.25
3400	6.46	6.87	7.29	7.70	8.13	8.59	9.04	9.50	9.95	10.4	10.84	11.29	11.74	12.19	12.62	13.06	13.99	14.99
3500	7.02	7.45	7.86	8.30	8.73	9.20	9.67	10.14	10.6	11.07	11.53	11.99	12.45	12.91	13.36	13.82	14.71	15.73

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B4. Type 4 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
600	0.09	0.18	0.28	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
700	0.12	0.21	0.31	0.43	*	*	*	*	*	*	*	*	*	*	*	*	*	*
800	0.14	0.24	0.35	0.47	0.61	*	*	*	*	*	*	*	*	*	*	*	*	*
900	0.18	0.28	0.40	0.53	0.66	0.81	0.97	*	*	*	*	*	*	*	*	*	*	*
1000	0.22	0.33	0.46	0.59	0.73	0.88	1.05	1.22	1.40	*	*	*	*	*	*	*	*	*
1100	0.26	0.39	0.52	0.66	0.81	0.96	1.13	1.31	1.49	1.68	1.88	*	*	*	*	*	*	*
1200	0.32	0.45	0.59	0.74	0.89	1.05	1.23	1.41	1.59	1.79	2.00	2.21	2.42	*	*	*	*	*
1300	0.38	0.52	0.67	0.82	0.99	1.16	1.33	1.52	1.71	1.91	2.12	2.34	2.56	2.79	3.02	*	*	*
1400	0.45	0.60	0.76	0.92	1.09	1.27	1.45	1.64	1.84	2.05	2.26	2.47	2.70	2.94	3.18	3.42	*	*
1500	0.53	0.69	0.86	1.03	1.21	1.39	1.58	1.78	1.98	2.19	2.41	2.64	2.86	3.10	3.34	3.60	4.11	4.65
1600	0.62	0.79	0.97	1.15	1.33	1.53	1.72	1.93	2.14	2.35	2.58	2.81	3.04	3.28	3.53	3.78	4.31	4.86
1700	0.72	0.90	1.09	1.28	1.47	1.67	1.88	2.09	2.31	2.53	2.75	2.99	3.23	3.48	3.73	3.99	4.51	5.07
1800	0.84	1.03	1.22	1.42	1.62	1.83	2.04	2.26	2.49	2.72	2.95	3.19	3.43	3.69	3.95	4.21	4.75	5.31
1900	0.96	1.16	1.36	1.57	1.79	2.00	2.22	2.45	2.68	2.92	3.16	3.41	3.65	3.91	4.18	4.45	5.00	5.57
2000	1.10	1.31	1.52	1.74	1.96	2.19	2.42	2.65	2.89	3.13	3.39	3.64	3.90	4.16	4.42	4.69	5.27	5.85
2100	1.25	1.47	1.69	1.92	2.15	2.39	2.63	2.87	3.11	3.36	3.62	3.89	4.15	4.42	4.69	4.97	5.54	6.14
2200	1.41	1.64	1.88	2.11	2.36	2.60	2.85	3.10	3.35	3.61	3.88	4.15	4.42	4.70	4.98	5.26	5.84	6.45
2300	1.59	1.83	2.08	2.32	2.57	2.83	3.09	3.35	3.61	3.88	4.15	4.42	4.70	4.99	5.28	5.57	6.17	6.77
2400	1.78	2.04	2.29	2.55	2.81	3.07	3.34	3.61	3.88	4.16	4.44	4.72	5.00	5.30	5.60	5.90	6.51	7.13
2500	1.99	2.26	2.52	2.79	3.06	3.33	3.61	3.89	4.17	4.45	4.74	5.03	5.33	5.63	5.93	6.24	6.87	7.51
2600	2.22	2.49	2.77	3.04	3.32	3.61	3.89	4.18	4.47	4.77	5.07	5.37	5.67	5.98	6.28	6.60	7.25	7.91
2700	2.47	2.75	3.03	3.32	3.61	3.90	4.20	4.49	4.79	5.10	5.41	5.71	6.03	6.34	6.66	6.98	7.64	8.32
2800	2.73	3.02	3.31	3.61	3.91	4.21	4.52	4.83	5.13	5.45	5.76	6.08	6.40	6.73	7.05	7.38	8.05	8.74
2900	3.01	3.31	3.62	3.92	4.23	4.54	4.86	5.17	5.49	5.82	6.14	6.47	6.80	7.13	7.47	7.81	8.49	9.19
3000	3.31	3.62	3.94	4.25	4.57	4.89	5.22	5.54	5.87	6.21	6.54	6.88	7.22	7.56	7.90	8.25	8.95	9.66

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B5. Type 5 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
800	0.13	0.23	0.36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
900	0.15	0.27	0.40	0.54	0.70	*	*	*	*	*	*	*	*	*	*	*	*	*
1000	0.18	0.30	0.44	0.59	0.75	0.93	*	*	*	*	*	*	*	*	*	*	*	*
1100	0.22	0.35	0.49	0.64	0.81	0.99	1.19	*	*	*	*	*	*	*	*	*	*	*
1200	0.26	0.39	0.54	0.70	0.88	1.06	1.26	1.47	*	*	*	*	*	*	*	*	*	*
1300	0.30	0.45	0.61	0.77	0.95	1.14	1.34	1.55	1.78	2.01	*	*	*	*	*	*	*	*
1400	0.35	0.51	0.67	0.85	1.03	1.23	1.44	1.65	1.88	2.11	2.36	2.61	*	*	*	*	*	*
1500	0.41	0.58	0.75	0.93	1.12	1.32	1.54	1.76	1.98	2.22	2.48	2.73	3.00	*	*	*	*	*
1600	0.48	0.65	0.83	1.02	1.22	1.43	1.64	1.87	2.11	2.35	2.60	2.87	3.14	3.42	3.70	*	*	*
1700	0.55	0.73	0.92	1.12	1.33	1.54	1.76	1.99	2.24	2.49	2.74	3.00	3.28	3.57	3.86	4.16	*	*
1800	0.63	0.82	1.02	1.23	1.44	1.66	1.89	2.13	2.37	2.63	2.90	3.17	3.44	3.72	4.02	4.33	4.95	5.60
1900	0.71	0.92	1.13	1.34	1.57	1.79	2.03	2.28	2.53	2.79	3.06	3.34	3.62	3.90	4.20	4.50	5.15	5.81
2000	0.81	1.02	1.24	1.47	1.70	1.93	2.18	2.43	2.69	2.95	3.22	3.51	3.80	4.10	4.40	4.70	5.34	6.02
2100	0.92	1.14	1.37	1.60	1.84	2.09	2.34	2.60	2.86	3.13	3.41	3.70	4.00	4.30	4.61	4.92	5.56	6.24
2200	1.03	1.26	1.50	1.75	2.00	2.25	2.51	2.77	3.05	3.33	3.61	3.90	4.20	4.51	4.83	5.15	5.81	6.48
2300	1.15	1.40	1.64	1.90	2.16	2.42	2.69	2.96	3.24	3.53	3.82	4.12	4.42	4.73	5.05	5.39	6.06	6.75
2400	1.29	1.54	1.80	2.06	2.33	2.60	2.88	3.16	3.45	3.74	4.04	4.35	4.66	4.98	5.29	5.63	6.32	7.03
2500	1.44	1.70	1.97	2.24	2.52	2.80	3.08	3.37	3.67	3.97	4.28	4.59	4.91	5.24	5.56	5.89	6.59	7.31
2600	1.59	1.87	2.14	2.43	2.71	3.00	3.30	3.60	3.90	4.21	4.52	4.84	5.18	5.50	5.84	6.18	6.87	7.61
2700	1.76	2.04	2.33	2.62	2.92	3.22	3.52	3.83	4.14	4.46	4.78	5.11	5.45	5.79	6.13	6.48	7.18	7.92
2800	1.94	2.24	2.53	2.83	3.14	3.45	3.76	4.08	4.40	4.73	5.06	5.39	5.73	6.08	6.43	6.79	7.51	8.25
2900	2.14	2.44	2.75	3.06	3.37	3.69	4.02	4.34	4.67	5.01	5.34	5.69	6.03	6.39	6.75	7.12	7.85	8.61
3000	2.34	2.66	2.97	3.30	3.62	3.95	4.28	4.62	4.96	5.30	5.65	6.00	6.35	6.71	7.08	7.45	8.21	8.99
3100	2.56	2.89	3.21	3.54	3.88	4.22	4.56	4.91	5.25	5.61	5.96	6.32	6.68	7.05	7.42	7.81	8.58	9.37
3200	2.80	3.13	3.47	3.81	4.15	4.50	4.85	5.21	5.57	5.93	6.29	6.66	7.04	7.41	7.79	8.17	8.97	9.77
3300	3.05	3.39	3.74	4.09	4.44	4.80	5.16	5.53	5.89	6.27	6.64	7.01	7.40	7.78	8.17	8.56	9.36	10.19
3400	3.31	3.67	4.02	4.38	4.75	5.11	5.48	5.86	6.24	6.61	7.00	7.39	7.77	8.17	8.56	8.96	9.77	10.61
3500	3.59	3.96	4.32	4.69	5.06	5.44	5.82	6.2	6.59	6.98	7.38	7.77	8.17	8.57	8.98	9.38	10.21	11.06
3600	3.89	4.26	4.64	5.02	5.40	5.79	6.17	6.57	6.97	7.36	7.77	8.18	8.58	8.99	9.41	9.82	10.67	11.52

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B6. Type 6 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
1000	0.16	0.29	0.45	0.62	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1150	0.20	0.34	0.50	0.69	0.88	*	*	*	*	*	*	*	*	*	*	*	*	*
1300	0.25	0.40	0.57	0.76	0.96	1.19	*	*	*	*	*	*	*	*	*	*	*	*
1450	0.31	0.47	0.65	0.85	1.06	1.29	1.53	1.78	*	*	*	*	*	*	*	*	*	*
1600	0.37	0.55	0.74	0.95	1.17	1.40	1.65	1.91	2.19	2.48	*	*	*	*	*	*	*	*
1750	0.45	0.64	0.85	1.06	1.29	1.54	1.79	2.06	2.34	2.63	2.94	3.25	*	*	*	*	*	*
1900	0.54	0.75	0.96	1.19	1.43	1.68	1.95	2.22	2.51	2.80	3.12	3.44	3.77	4.11	*	*	*	*
2050	0.64	0.86	1.09	1.33	1.59	1.85	2.11	2.40	2.70	3.00	3.31	3.63	3.98	4.33	4.69	5.05	*	*
2200	0.76	0.99	1.24	1.49	1.75	2.03	2.31	2.59	2.90	3.22	3.54	3.87	4.21	4.56	4.93	5.30	6.08	*
2350	0.89	1.14	1.40	1.66	1.94	2.22	2.52	2.82	3.12	3.44	3.78	4.13	4.47	4.83	5.19	5.57	6.36	7.18
2500	1.03	1.30	1.57	1.85	2.14	2.43	2.74	3.05	3.37	3.70	4.04	4.39	4.75	5.12	5.49	5.87	6.66	7.50
2650	1.19	1.48	1.76	2.06	2.36	2.67	2.98	3.30	3.64	3.98	4.32	4.68	5.05	5.43	5.82	6.21	7.00	7.83
2800	1.38	1.67	1.97	2.28	2.60	2.92	3.24	3.58	3.92	4.28	4.68	5.00	5.37	5.75	6.15	6.55	7.38	8.22
2950	1.58	1.89	2.20	2.53	2.85	3.19	3.53	3.88	4.21	4.60	4.96	5.34	5.72	6.11	6.50	6.92	7.76	8.63
3100	1.79	2.12	2.45	2.79	3.13	3.48	3.83	4.19	4.56	4.93	5.31	5.70	6.10	6.50	6.90	7.31	8.17	9.07
3250	2.03	2.38	2.72	3.07	3.43	3.79	4.16	4.53	4.91	5.29	5.69	6.09	6.50	6.91	7.32	7.75	8.60	9.51
3400	2.30	2.65	3.01	3.38	3.75	4.12	4.51	4.90	5.29	5.68	6.08	6.49	6.91	7.34	7.77	8.20	9.09	9.98
3550	2.58	2.95	3.33	3.70	4.09	4.48	4.88	5.28	5.68	6.09	6.51	6.93	7.35	7.79	8.23	8.68	9.59	10.52
3700	2.89	3.27	3.66	4.06	4.46	4.86	5.27	5.69	6.11	6.53	6.96	7.39	7.83	8.27	8.73	9.19	10.13	11.07
3850	3.22	3.62	4.02	4.43	4.85	5.27	5.69	6.12	6.56	6.99	7.43	7.88	8.33	8.78	9.25	9.72	10.68	11.66
4000	3.58	3.99	4.41	4.84	5.27	5.70	6.14	6.59	7.03	7.48	7.94	8.39	8.86	9.33	9.80	10.27	11.26	12.27
4150	3.96	4.39	4.83	5.27	5.71	6.16	6.61	7.07	7.53	8.00	8.46	8.94	9.42	9.90	10.38	10.87	11.86	12.90
4300	4.37	4.82	5.27	5.73	6.19	6.65	7.12	7.58	8.06	8.54	9.02	9.51	10.00	10.5	10.99	11.50	12.52	13.56
4450	4.81	5.28	5.75	6.21	6.68	7.16	7.65	8.13	8.62	9.11	9.61	10.11	10.62	11.13	11.64	12.16	13.20	14.25

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B7. Type 7 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
1200	0.19	0.35	0.54	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1350	0.23	0.40	0.59	0.81	1.05	*	*	*	*	*	*	*	*	*	*	*	*	*
1500	0.28	0.46	0.66	0.88	1.13	1.39	*	*	*	*	*	*	*	*	*	*	*	*
1650	0.33	0.52	0.73	0.97	1.21	1.49	1.76	*	*	*	*	*	*	*	*	*	*	*
1800	0.39	0.59	0.82	1.06	1.32	1.59	1.89	2.20	*	*	*	*	*	*	*	*	*	*
1950	0.46	0.68	0.91	1.16	1.43	1.71	2.01	2.33	2.66	3.01	*	*	*	*	*	*	*	*
2100	0.53	0.77	1.01	1.27	1.55	1.84	2.15	2.47	2.81	3.16	3.53	3.91	*	*	*	*	*	*
2250	0.62	0.87	1.13	1.40	1.69	1.98	2.30	2.64	2.97	3.33	3.71	4.10	4.49	4.90	*	*	*	*
2400	0.72	0.98	1.25	1.54	1.83	2.14	2.46	2.81	3.16	3.52	3.89	4.29	4.70	5.12	5.54	*	*	*
2550	0.83	1.10	1.39	1.68	1.99	2.31	2.65	2.99	3.36	3.73	4.11	4.50	4.91	5.34	5.78	6.23	*	*
2700	0.94	1.24	1.54	1.85	2.16	2.50	2.84	3.20	3.56	3.95	4.34	4.75	5.16	5.57	6.03	6.49	7.42	8.39
2850	1.08	1.38	1.70	2.02	2.35	2.70	3.05	3.42	3.79	4.18	4.59	5.00	5.42	5.85	6.30	6.75	7.71	8.71
3000	1.22	1.54	1.87	2.21	2.55	2.91	3.28	3.65	4.04	4.43	4.84	5.27	5.70	6.15	6.60	7.06	8.01	9.02
3150	1.38	1.72	2.06	2.41	2.77	3.14	3.51	3.90	4.30	4.71	5.12	5.55	5.99	6.45	6.91	7.38	8.34	9.35
3300	1.56	1.90	2.26	2.63	3.00	3.38	3.77	4.17	4.58	5.00	5.42	5.86	6.30	6.76	7.24	7.72	8.71	9.72
3450	1.74	2.11	2.48	2.86	3.25	3.64	4.04	4.45	4.87	5.31	5.74	6.19	6.64	7.10	7.58	8.08	9.08	10.12
3600	1.95	2.33	2.71	3.11	3.51	3.92	4.33	4.75	5.18	5.63	6.08	6.53	7.00	7.47	7.94	8.44	9.47	10.54
3750	2.17	2.56	2.96	3.37	3.79	4.21	4.64	5.07	5.51	5.96	6.42	6.90	7.37	7.86	8.35	8.85	9.89	10.96
3900	2.4	2.81	3.23	3.65	4.08	4.52	4.96	5.41	5.86	6.32	6.80	7.28	7.77	8.27	8.77	9.28	10.31	11.42
4050	2.66	3.08	3.52	3.95	4.40	4.85	5.30	5.77	6.23	6.71	7.19	7.68	8.18	8.69	9.21	9.73	10.78	11.88
4200	2.94	3.38	3.82	4.27	4.73	5.19	5.66	6.14	6.62	7.11	7.60	8.10	8.62	9.14	9.66	10.20	11.28	12.38
4350	3.23	3.68	4.14	4.61	5.08	5.56	6.05	6.53	7.03	7.53	8.04	8.55	9.06	9.60	10.14	10.69	11.80	12.93
4500	3.54	4.01	4.48	4.96	5.45	5.94	6.45	6.95	7.46	7.97	8.49	9.02	9.54	10.09	10.64	11.20	12.34	13.49
4650	3.88	4.36	4.85	5.35	5.85	6.35	6.86	7.38	7.90	8.44	8.97	9.51	10.05	10.60	11.15	11.73	12.89	14.07
4800	4.23	4.73	5.24	5.74	6.26	6.78	7.30	7.84	8.38	8.92	9.46	10.01	10.58	11.14	11.71	12.28	13.46	14.67
4950	4.61	5.12	5.64	6.17	6.70	7.23	7.77	8.32	8.87	9.43	9.99	10.56	11.13	11.70	12.28	12.87	14.07	15.30
5100	5.01	5.53	6.07	6.61	7.16	7.70	8.26	8.82	9.39	9.96	10.53	11.11	11.70	12.29	12.88	13.47	14.69	15.95
5250	5.43	5.97	6.52	7.08	7.64	8.20	8.77	9.35	9.93	10.51	11.10	11.69	12.29	12.90	13.50	14.11	15.35	16.63
5400	5.88	6.44	7.00	7.57	8.15	8.72	9.31	9.90	10.49	11.08	11.69	12.29	12.91	13.53	14.15	14.78	16.04	17.32

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B8. Type 8 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
1500	0.24	0.44	0.67	0.93	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1700	0.30	0.51	0.75	1.01	1.31	*	*	*	*	*	*	*	*	*	*	*	*	*
1900	0.36	0.59	0.84	1.11	1.42	1.74	*	*	*	*	*	*	*	*	*	*	*	*
2100	0.43	0.68	0.94	1.23	1.54	1.87	2.23	2.6	*	*	*	*	*	*	*	*	*	*
2300	0.52	0.78	1.06	1.36	1.68	2.02	2.38	2.77	3.18	*	*	*	*	*	*	*	*	*
2500	0.62	0.90	1.19	1.51	1.84	2.19	2.57	2.95	3.37	3.8	4.24	*	*	*	*	*	*	*
2700	0.73	1.03	1.34	1.67	2.01	2.37	2.76	3.16	3.57	4.01	4.48	4.94	5.43	*	*	*	*	*
2900	0.85	1.17	1.50	1.84	2.20	2.58	2.98	3.39	3.82	4.26	4.71	5.20	5.70	6.21	6.73	*	*	*
3100	1.00	1.33	1.68	2.04	2.42	2.81	3.21	3.63	4.08	4.54	5.00	5.48	5.98	6.50	7.05	7.59	*	*
3300	1.16	1.51	1.88	2.26	2.65	3.06	3.47	3.91	4.35	4.82	5.31	5.80	6.30	6.81	7.37	7.93	9.08	10.26
3500	1.33	1.70	2.09	2.49	2.89	3.32	3.75	4.2	4.66	5.13	5.64	6.14	6.66	7.18	7.72	8.28	9.46	10.67
3700	1.53	1.92	2.33	2.74	3.17	3.60	4.05	4.52	4.99	5.48	5.97	6.50	7.03	7.57	8.13	8.69	9.85	11.11
3900	1.74	2.16	2.58	3.01	3.46	3.91	4.37	4.86	5.34	5.85	6.35	6.87	7.42	7.99	8.56	9.13	10.31	11.54
4100	1.98	2.41	2.86	3.31	3.77	4.24	4.72	5.21	5.72	6.24	6.76	7.30	7.84	8.41	8.99	9.59	10.80	12.05
4300	2.24	2.69	3.15	3.63	4.11	4.60	5.09	5.60	6.12	6.66	7.20	7.75	8.30	8.87	9.46	10.07	11.32	12.59
4500	2.52	3.00	3.48	3.97	4.47	4.98	5.49	6.02	6.55	7.09	7.65	8.22	8.80	9.39	9.97	10.57	11.85	13.17
4700	2.83	3.32	3.82	4.33	4.85	5.38	5.91	6.45	7.00	7.56	8.14	8.72	9.32	9.91	10.53	11.13	12.41	13.75
4900	3.16	3.67	4.19	4.72	5.26	5.81	6.36	6.92	7.49	8.06	8.65	9.25	9.86	10.48	11.10	11.73	13.02	14.36
5100	3.52	4.05	4.59	5.14	5.70	6.26	6.84	7.41	8.00	8.59	9.19	9.80	10.42	11.06	11.70	12.35	13.68	15.01
5300	3.91	4.46	5.02	5.59	6.17	6.75	7.34	7.93	8.54	9.15	9.77	10.39	11.02	11.67	12.33	13.00	14.36	15.74
5500	4.32	4.90	5.47	6.06	6.66	7.26	7.87	8.49	9.11	9.74	10.37	11.01	11.67	12.32	13.00	13.68	15.07	16.47
5700	4.76	5.36	5.96	6.57	7.18	7.80	8.43	9.07	9.71	10.36	11.00	11.67	12.33	13.01	13.68	14.39	15.81	17.26
5900	5.24	5.85	6.48	7.10	7.73	8.38	9.02	9.68	10.34	11.01	11.68	12.36	13.04	13.73	14.43	15.12	16.58	18.06
6100	5.75	6.38	7.03	7.67	8.32	8.99	9.65	10.33	11.00	11.68	12.38	13.07	13.78	14.48	15.19	15.92	17.39	18.90
6300	6.29	6.95	7.61	8.28	8.94	9.62	10.3	11.00	11.70	12.40	13.11	13.83	14.55	15.28	16.01	16.74	18.23	19.78
6500	6.86	7.54	8.22	8.91	9.60	10.29	11.0	11.70	12.43	13.16	13.88	14.61	15.34	16.10	16.84	17.61	19.14	20.69

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B9. Type 9 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
2000	0.34	0.59	0.88	1.20	1.55	*	*	*	*	*	*	*	*	*	*	*	*	*
2250	0.42	0.69	0.99	1.32	1.68	2.07	*	*	*	*	*	*	*	*	*	*	*	*
2500	0.51	0.80	1.11	1.46	1.83	2.23	2.66	*	*	*	*	*	*	*	*	*	*	*
2750	0.62	0.93	1.26	1.62	2.01	2.42	2.85	3.32	3.80	*	*	*	*	*	*	*	*	*
3000	0.74	1.07	1.43	1.81	2.20	2.63	3.08	3.54	4.04	4.56	5.09	*	*	*	*	*	*	*
3250	0.88	1.24	1.61	2.01	2.42	2.86	3.33	3.81	4.30	4.83	5.39	5.94	6.53	*	*	*	*	*
3500	1.04	1.42	1.82	2.23	2.67	3.12	3.59	4.09	4.61	5.14	5.68	6.27	6.87	7.48	8.10	*	*	*
3750	1.22	1.62	2.04	2.48	2.93	3.41	3.89	4.40	4.93	5.48	6.05	6.62	7.22	7.85	8.49	9.15	*	*
4000	1.42	1.85	2.29	2.75	3.22	3.71	4.22	4.74	5.28	5.85	6.43	7.03	7.63	8.25	8.91	9.59	10.96	12.40
4250	1.64	2.09	2.57	3.04	3.54	4.05	4.58	5.12	5.67	6.24	6.84	7.46	8.08	8.72	9.37	10.03	11.46	12.92
4500	1.89	2.37	2.87	3.37	3.88	4.41	4.96	5.52	6.10	6.68	7.28	7.91	8.56	9.21	9.88	10.56	11.95	13.45
4750	2.17	2.67	3.19	3.72	4.25	4.81	5.36	5.94	6.54	7.15	7.76	8.39	9.04	9.73	10.41	11.11	12.55	14.01
5000	2.47	3.00	3.54	4.09	4.65	5.22	5.81	6.40	7.02	7.65	8.29	8.93	9.59	10.27	10.98	11.70	13.17	14.68
5250	2.80	3.36	3.92	4.50	5.08	5.68	6.29	6.90	7.53	8.18	8.84	9.51	10.18	10.87	11.57	12.31	13.82	15.37
5500	3.17	3.75	4.33	4.93	5.54	6.16	6.79	7.43	8.08	8.74	9.43	10.11	10.81	11.52	12.24	12.96	14.49	16.08
5750	3.57	4.17	4.78	5.40	6.04	6.68	7.33	7.99	8.67	9.34	10.04	10.75	11.47	12.20	12.94	13.68	15.21	16.84
6000	4.00	4.62	5.26	5.91	6.56	7.23	7.91	8.59	9.28	9.98	10.70	11.42	12.17	12.91	13.67	14.45	16.01	17.61
6250	4.46	5.11	5.78	6.45	7.13	7.82	8.52	9.22	9.93	10.66	11.39	12.14	12.89	13.67	14.44	15.24	16.84	18.47
6500	4.97	5.65	6.33	7.02	7.73	8.44	9.17	9.90	10.63	11.38	12.13	12.89	13.67	14.45	15.25	16.07	17.72	19.38
6750	5.51	6.21	6.93	7.64	8.36	9.10	9.85	10.61	11.36	12.13	12.91	13.70	14.48	15.29	16.09	16.94	18.63	20.35
7000	6.08	6.81	7.55	8.29	9.04	9.81	10.58	11.36	12.14	12.92	13.73	14.54	15.35	16.18	17.01	17.84	19.57	21.35
7250	6.71	7.46	8.23	9.00	9.77	10.56	11.34	12.14	12.95	13.77	14.59	15.42	16.27	17.10	17.94	18.81	20.56	22.37
7500	7.38	8.15	8.93	9.74	10.54	11.34	12.15	12.97	13.81	14.65	15.49	16.35	17.21	18.08	18.95	19.83	21.61	23.46
7750	8.08	8.88	9.70	10.52	11.34	12.17	13.00	13.86	14.72	15.59	16.44	17.32	18.20	19.09	20.00	20.89	22.72	24.58
8000	8.84	9.66	10.5	11.34	12.19	13.05	13.91	14.79	15.66	16.55	17.44	18.35	19.26	20.17	21.09	22.01	23.88	25.78

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B10. Type 10 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
2300	0.38	0.67	1.01	1.40	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2600	0.47	0.79	1.14	1.53	1.97	*	*	*	*	*	*	*	*	*	*	*	*	*
2900	0.57	0.91	1.28	1.70	2.13	2.62	3.13	*	*	*	*	*	*	*	*	*	*	*
3200	0.69	1.05	1.45	1.88	2.34	2.82	3.35	3.91	*	*	*	*	*	*	*	*	*	*
3500	0.83	1.22	1.64	2.08	2.56	3.07	3.60	4.17	4.77	5.38	*	*	*	*	*	*	*	*
3800	0.99	1.41	1.85	2.32	2.81	3.34	3.89	4.46	5.06	5.70	6.36	7.03	*	*	*	*	*	*
4100	1.16	1.62	2.08	2.58	3.09	3.63	4.20	4.80	5.41	6.04	6.71	7.41	8.12	8.86	*	*	*	*
4400	1.37	1.85	2.34	2.86	3.40	3.96	4.54	5.15	5.79	6.44	7.11	7.80	8.54	9.30	10.07	10.84	*	*
4700	1.60	2.10	2.63	3.17	3.73	4.32	4.92	5.53	6.19	6.87	7.57	8.27	9.00	9.76	10.55	11.35	13.00	*
5000	1.86	2.39	2.95	3.51	4.09	4.70	5.33	5.98	6.63	7.32	8.05	8.78	9.52	10.28	11.05	11.87	13.57	15.34
5300	2.14	2.70	3.29	3.88	4.49	5.12	5.77	6.44	7.12	7.81	8.54	9.30	10.08	10.87	11.65	12.47	14.16	15.97
5600	2.46	3.05	3.66	4.29	4.92	5.58	6.24	6.94	7.64	8.37	9.10	9.86	10.65	11.46	12.29	13.12	14.82	16.63
5900	2.81	3.43	4.07	4.73	5.38	6.06	6.76	7.47	8.20	8.95	9.71	10.49	11.27	12.10	12.95	13.81	15.56	17.36
6200	3.19	3.84	4.51	5.19	5.88	6.59	7.31	8.04	8.79	9.57	10.35	11.14	11.96	12.77	13.63	14.52	16.31	18.17
6500	3.60	4.29	4.99	5.69	6.42	7.16	7.89	8.65	9.42	10.22	11.04	11.85	12.69	13.54	14.38	15.25	17.11	19.02
6800	4.06	4.78	5.5	6.24	6.99	7.76	8.52	9.31	10.11	10.91	11.75	12.59	13.46	14.34	15.21	16.11	17.95	19.90
7100	4.56	5.30	6.06	6.83	7.60	8.39	9.19	10.00	10.83	11.67	12.51	13.37	14.27	15.17	16.08	16.98	18.84	20.81
7400	5.10	5.86	6.65	7.44	8.25	9.08	9.90	10.75	11.60	12.46	13.32	14.20	15.12	16.05	16.97	17.91	19.83	21.78
7700	5.68	6.48	7.28	8.11	8.95	9.80	10.66	11.53	12.41	13.29	14.19	15.08	16.01	16.96	17.92	18.89	20.86	22.85
8000	6.30	7.13	7.97	8.83	9.70	10.56	11.46	12.35	13.25	14.17	15.09	16.02	16.97	17.93	18.90	19.91	21.92	23.98
8300	6.96	7.83	8.70	9.59	10.47	11.38	12.29	13.23	14.15	15.09	16.05	17.02	17.98	18.96	19.94	20.96	23.04	25.14
8600	7.68	8.57	9.49	10.39	11.32	12.25	13.19	14.15	15.11	16.07	17.05	18.03	19.03	20.05	21.07	22.09	24.20	26.37
8900	8.45	9.37	10.31	11.26	12.2	13.17	14.14	15.12	16.11	17.10	18.11	19.14	20.15	21.18	22.23	23.27	25.40	27.61
9200	9.27	10.22	11.19	12.15	13.14	14.14	15.14	16.13	17.15	18.18	19.22	20.26	21.32	22.38	23.45	24.52	26.70	28.95
9500	10.13	11.12	12.13	13.11	14.13	15.15	16.18	17.22	18.25	19.32	20.39	21.45	22.52	23.62	24.70	25.81	28.03	30.30
9800	11.06	12.09	13.11	14.15	15.17	16.22	17.29	18.35	19.43	20.52	21.59	22.69	23.80	24.91	26.03	27.18	29.45	31.76

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B11. Type 11 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
2700	0.32	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3050	0.39	0.68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3400	0.46	0.78	1.13	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3750	0.55	0.89	1.26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4100	0.65	1.02	1.41	1.83	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4450	0.77	1.15	1.57	2.01	2.48	*	*	*	*	*	*	*	*	*	*	*	*	*
4800	0.89	1.31	1.74	2.21	2.70	3.21	*	*	*	*	*	*	*	*	*	*	*	*
5150	1.04	1.48	1.94	2.42	2.93	3.46	4.01	*	*	*	*	*	*	*	*	*	*	*
5500	1.20	1.67	2.16	2.65	3.18	3.74	4.30	4.89	*	*	*	*	*	*	*	*	*	*
5850	1.38	1.88	2.39	2.91	3.46	4.03	4.61	5.23	5.85	*	*	*	*	*	*	*	*	*
6200	1.58	2.10	2.65	3.19	3.75	4.35	4.96	5.59	6.23	6.89	*	*	*	*	*	*	*	*
6550	1.81	2.35	2.92	3.49	4.08	4.69	5.32	5.97	6.63	7.31	8.01	*	*	*	*	*	*	*
6900	2.05	2.62	3.21	3.82	4.43	5.05	5.70	6.38	7.06	7.77	8.48	9.21	9.96	*	*	*	*	*
7250	2.33	2.90	3.52	4.16	4.80	5.44	6.12	6.82	7.52	8.25	8.97	9.72	10.50	11.28	*	*	*	*
7600	2.62	3.22	3.87	4.53	5.21	5.87	6.55	7.27	8.01	8.75	9.50	10.27	11.06	11.87	12.68	*	*	*
7950	2.94	3.57	4.23	4.93	5.62	6.32	7.02	7.75	8.51	9.28	10.06	10.85	11.66	12.47	13.31	14.17	*	*
8300	3.29	3.94	4.62	5.34	6.07	6.80	7.53	8.27	9.03	9.83	10.64	11.46	12.28	13.12	13.97	14.82	16.62	*
8650	3.67	4.33	5.04	5.79	6.54	7.31	8.06	8.84	9.61	10.40	11.25	12.08	12.93	13.79	14.68	15.55	17.37	19.24
9000	4.08	4.77	5.50	6.26	7.04	7.84	8.63	9.43	10.23	11.03	11.88	12.74	13.62	14.51	15.40	16.31	18.16	20.04
9350	4.52	5.23	5.98	6.77	7.58	8.39	9.23	10.04	10.87	11.71	12.56	13.42	14.33	15.23	16.15	17.08	18.97	20.91
9700	4.99	5.73	6.48	7.31	8.14	8.99	9.85	10.69	11.54	12.40	13.28	14.16	15.06	16.00	16.95	17.91	19.83	21.83
10050	5.49	6.26	7.05	7.87	8.73	9.59	10.49	11.37	12.27	13.14	14.03	14.94	15.84	16.82	17.77	18.77	20.75	22.78
10400	6.03	6.82	7.63	8.48	9.36	10.25	11.17	12.09	13.00	13.91	14.83	15.75	16.69	17.63	18.62	19.65	21.66	23.75
10750	6.61	7.43	8.26	9.11	10.02	10.95	11.87	12.83	13.78	14.73	15.66	16.62	17.59	18.54	19.52	20.55	22.63	24.75
11100	7.22	8.07	8.91	9.78	10.72	11.67	12.62	13.6	14.60	15.58	16.55	17.52	18.49	19.50	20.49	21.52	23.63	25.80
11450	7.87	8.74	9.61	10.52	11.46	12.43	13.43	14.42	15.43	16.43	17.44	18.44	19.45	20.47	21.49	22.55	24.68	26.89
11800	8.56	9.46	10.36	11.27	12.22	13.23	14.24	15.27	16.30	17.34	18.39	19.43	20.47	21.50	22.55	23.61	25.73	28.01

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B12. Type 12 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
3300	0.39	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3700	0.46	0.82	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4100	0.55	0.93	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4500	0.64	1.05	1.51	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4900	0.75	1.18	1.67	2.18	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5300	0.87	1.34	1.84	2.37	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5700	1.00	1.50	2.03	2.59	3.18	*	*	*	*	*	*	*	*	*	*	*	*	*
6100	1.15	1.69	2.23	2.82	3.43	4.07	*	*	*	*	*	*	*	*	*	*	*	*
6500	1.32	1.88	2.45	3.06	3.71	4.37	5.06	*	*	*	*	*	*	*	*	*	*	*
6900	1.51	2.10	2.71	3.32	4.00	4.69	5.39	6.13	*	*	*	*	*	*	*	*	*	*
7300	1.72	2.33	2.97	3.62	4.31	5.03	5.76	6.51	7.30	*	*	*	*	*	*	*	*	*
7700	1.94	2.59	3.27	3.94	4.65	5.38	6.15	6.92	7.72	8.57	*	*	*	*	*	*	*	*
8100	2.20	2.86	3.57	4.29	5.00	5.77	6.56	7.36	8.19	9.03	9.91	*	*	*	*	*	*	*
8500	2.47	3.17	3.90	4.65	5.40	6.17	6.98	7.82	8.66	9.53	10.43	11.36	*	*	*	*	*	*
8900	2.77	3.48	4.24	5.03	5.82	6.61	7.43	8.31	9.17	10.07	10.90	11.91	12.87	*	*	*	*	*
9300	3.09	3.83	4.62	5.45	6.26	7.08	7.92	8.80	9.72	10.63	11.58	12.53	13.50	14.50	15.52	*	*	*
9700	3.45	4.21	5.02	5.88	6.73	7.58	8.45	9.33	10.27	11.21	12.19	13.15	14.17	15.17	16.20	17.25	*	*
10100	3.82	4.60	5.46	6.33	7.23	8.11	9.01	9.92	10.85	11.84	12.83	13.82	14.84	15.88	16.94	18.00	*	*
10500	4.23	5.05	5.91	6.82	7.74	8.68	9.60	10.53	11.48	12.48	13.49	14.54	15.56	16.64	17.70	18.80	21.05	*
10900	4.67	5.51	6.40	7.34	8.28	9.25	10.22	11.18	12.15	13.15	14.19	15.25	16.34	17.42	18.51	19.61	21.87	24.25
11300	5.14	6.01	6.91	7.88	8.85	9.86	10.86	11.86	12.85	13.86	14.92	16.02	17.11	18.22	19.35	20.48	22.78	25.20
11700	5.65	6.54	7.47	8.45	9.46	10.50	11.52	12.57	13.59	14.65	15.69	16.78	17.94	19.05	20.21	21.38	23.75	26.16
12100	6.18	7.11	8.04	9.07	10.11	11.16	12.25	13.30	14.37	15.43	16.52	17.62	18.76	19.94	21.13	22.30	24.73	27.22
12500	6.75	7.70	8.69	9.72	10.78	11.87	12.96	14.09	15.17	16.27	17.40	18.51	19.63	20.85	22.04	23.29	25.75	28.26
12900	7.36	8.33	9.34	10.40	11.48	12.59	13.74	14.87	16.00	17.14	18.27	19.46	20.62	21.79	23.02	24.26	26.79	29.36
13300	8.00	9.02	10.03	11.11	12.23	13.37	14.53	15.70	16.89	18.04	19.21	20.40	21.60	22.81	24.03	25.30	27.90	30.50
13700	8.67	9.72	10.77	11.85	13.02	14.18	15.39	16.59	17.79	19.01	20.19	21.41	22.62	23.87	25.08	26.37	29.00	31.71
14100	9.40	10.47	11.56	12.67	13.85	15.04	16.24	17.49	18.73	19.97	21.23	22.46	23.7	24.95	26.24	27.49	30.17	32.91
14500	10.17	11.25	12.38	13.51	14.7	15.92	17.16	18.42	19.70	20.99	22.26	23.54	24.82	26.11	27.4	28.73	31.37	34.18

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B13. Type 13 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
4500	0.56	1.00	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5000	0.66	1.13	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5500	0.78	1.28	1.84	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6000	0.91	1.44	2.04	2.66	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6500	1.05	1.63	2.25	2.90	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7000	1.22	1.84	2.48	3.17	3.90	*	*	*	*	*	*	*	*	*	*	*	*	*
7500	1.41	2.07	2.73	3.45	4.22	5.01	*	*	*	*	*	*	*	*	*	*	*	*
8000	1.62	2.31	3.10	3.77	4.56	5.37	6.22	*	*	*	*	*	*	*	*	*	*	*
8500	1.85	2.58	3.33	4.09	4.92	5.78	6.65	7.55	*	*	*	*	*	*	*	*	*	*
9000	2.10	2.87	3.67	4.46	5.30	6.20	7.09	8.04	9.01	*	*	*	*	*	*	*	*	*
9500	2.40	3.19	4.03	4.86	5.72	6.64	7.58	8.55	9.54	10.56	*	*	*	*	*	*	*	*
10000	2.71	3.53	4.41	5.29	6.18	7.13	8.08	9.10	10.10	11.14	12.22	*	*	*	*	*	*	*
10500	3.05	3.91	4.81	5.75	6.67	7.61	8.63	9.67	10.71	11.80	12.89	14.03	*	*	*	*	*	*
11000	3.43	4.31	5.25	6.23	7.19	8.17	9.21	10.26	11.35	12.45	13.58	14.73	15.91	*	*	*	*	*
11500	3.83	4.75	5.73	6.73	7.75	8.76	9.80	10.91	12.01	13.15	14.33	15.47	16.67	17.92	19.19	*	*	*
12000	4.27	5.21	6.22	7.29	8.34	9.40	10.46	11.55	12.72	13.91	15.10	16.29	17.5	18.74	20.06	21.35	*	*
12500	4.76	5.72	6.77	7.85	8.97	10.04	11.16	12.29	13.46	14.66	15.90	17.13	18.38	19.66	20.95	22.28	*	*
13000	5.26	6.27	7.35	8.46	9.61	10.74	11.91	13.06	14.23	15.48	16.72	17.99	19.29	20.61	21.94	23.25	26.07	*
13500	5.82	6.86	7.97	9.11	10.29	11.5	12.66	13.86	15.08	16.29	17.61	18.93	20.23	21.59	22.92	24.31	27.12	30.02
14000	6.40	7.48	8.61	9.79	11.02	12.25	13.47	14.73	15.96	17.21	18.49	19.85	21.24	22.60	23.97	25.40	28.24	31.18
14500	7.04	8.15	9.29	10.52	11.79	13.04	14.32	15.60	16.87	18.17	19.51	20.85	22.23	23.64	25.10	26.53	29.44	32.46
15000	7.71	8.87	10.03	11.30	12.59	13.90	15.21	16.53	17.86	19.17	20.55	21.87	23.31	24.76	26.22	27.69	30.69	33.73
15500	8.43	9.63	10.82	12.11	13.43	14.75	16.12	17.50	18.88	20.24	21.63	22.99	24.41	25.91	27.37	28.88	31.96	35.08
16000	9.20	10.42	11.64	12.96	14.30	15.68	17.10	18.52	19.94	21.31	22.75	24.16	25.62	27.05	28.60	30.16	33.27	36.48
16500	10.01	11.27	12.54	13.86	15.25	16.69	18.13	19.56	21.04	22.46	23.95	25.41	26.87	28.34	29.86	31.47	34.67	37.91
17000	10.86	12.15	13.46	14.82	16.24	17.70	19.15	20.67	22.17	23.65	25.14	26.65	28.16	29.68	31.25	32.76	36.05	39.37
17500	11.77	13.09	14.45	15.81	17.28	18.75	20.26	21.79	23.34	24.88	26.43	27.98	29.55	31.06	32.62	34.24	37.53	40.94
18000	12.75	14.10	15.49	16.87	18.35	19.89	21.45	22.99	24.55	26.17	27.75	29.36	30.92	32.53	34.15	36.76	39.05	42.48

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B14. Type 14 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
5100	0.61	1.13	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5750	0.74	1.29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6400	0.88	1.47	2.14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7050	1.04	1.67	2.37	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7700	1.23	1.91	2.65	3.43	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8350	1.44	2.17	2.95	3.78	4.65	*	*	*	*	*	*	*	*	*	*	*	*	*
9000	1.68	2.47	3.27	4.14	5.04	6.00	*	*	*	*	*	*	*	*	*	*	*	*
9650	1.94	2.79	3.63	4.53	5.49	6.47	7.51	*	*	*	*	*	*	*	*	*	*	*
10300	2.25	3.12	4.03	4.96	5.97	6.98	8.05	9.16	*	*	*	*	*	*	*	*	*	*
10950	2.58	3.50	4.47	5.46	6.48	7.54	8.54	9.78	10.95	*	*	*	*	*	*	*	*	*
11600	2.97	3.93	4.95	5.96	7.02	8.14	9.29	10.45	11.64	12.89	*	*	*	*	*	*	*	*
12250	3.37	4.38	5.45	6.53	7.62	8.76	9.93	11.15	12.40	13.66	14.99	*	*	*	*	*	*	*
12900	3.84	4.89	6.00	7.12	8.27	9.43	10.64	11.92	13.22	14.50	15.83	17.22	18.64	*	*	*	*	*
13550	4.34	5.42	6.58	7.76	8.97	10.16	11.42	12.72	14.04	15.42	16.75	18.17	19.63	21.09	*	*	*	*
14200	4.88	5.99	7.22	8.45	9.70	10.96	12.25	13.55	14.93	16.32	17.76	19.18	20.63	22.16	23.7	*	*	*
14850	5.49	6.65	7.88	9.18	10.51	11.80	13.11	14.45	15.86	17.31	18.75	20.28	21.78	23.31	24.86	26.47	*	*
15500	6.12	7.33	8.61	9.95	11.31	12.67	14.06	15.42	16.82	18.33	19.83	21.36	22.92	24.50	26.10	27.71	31.01	*
16150	6.83	8.08	9.38	10.77	12.20	13.63	15.04	16.47	17.94	19.39	20.95	22.54	24.16	25.74	27.39	29.05	32.39	35.93
16800	7.58	8.86	10.23	11.66	13.12	14.61	16.08	17.56	19.05	20.57	22.16	23.76	25.37	27.07	28.71	30.43	33.86	37.46
17450	8.39	9.72	11.10	12.60	14.10	15.62	17.20	18.71	20.26	21.79	23.40	25.01	26.69	28.44	30.14	31.85	35.39	38.97
18100	9.26	10.64	12.04	13.59	15.12	16.71	18.30	19.90	21.51	23.11	24.73	26.37	28.11	29.86	31.62	33.38	37.03	40.72
18750	10.19	11.61	13.09	14.64	16.24	17.85	19.51	21.19	22.82	24.48	26.16	27.80	29.51	31.33	33.14	34.96	38.65	42.44
19400	11.18	12.68	14.16	15.73	17.41	19.05	20.78	22.49	24.18	25.90	27.59	29.35	31.06	32.84	34.71	36.59	40.39	44.22
20050	12.26	13.77	15.32	16.93	18.64	20.35	22.10	23.80	25.64	27.38	29.13	30.96	32.73	34.50	36.33	38.26	42.18	46.12
20700	13.38	14.96	16.55	18.18	19.92	21.70	23.47	25.26	27.13	28.97	30.79	32.62	34.45	36.28	38.18	39.99	44.03	48.08
21350	14.56	16.19	17.85	19.51	21.26	23.07	24.90	26.76	28.64	30.60	32.44	34.34	36.16	38.13	40.01	41.96	45.92	50.09
22000	15.85	17.52	19.21	20.89	22.72	24.54	26.45	28.39	30.27	32.23	34.15	36.12	38.08	39.96	41.98	43.91	47.95	52.15

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B15. Type 15 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
6000	0.68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6800	0.82	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7600	0.97	1.68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8400	1.16	1.90	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9200	1.36	2.16	3.05	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10000	1.59	2.46	3.38	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10800	1.86	2.78	3.73	4.78	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11600	2.16	3.15	4.16	5.24	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12400	2.49	3.54	4.61	5.72	6.90	*	*	*	*	*	*	*	*	*	*	*	*	*
13200	2.88	3.96	5.10	6.26	7.47	8.79	*	*	*	*	*	*	*	*	*	*	*	*
14000	3.31	4.42	5.64	6.85	8.10	9.46	10.81	*	*	*	*	*	*	*	*	*	*	*
14800	3.79	4.94	6.21	7.48	8.77	10.15	11.57	13.04	*	*	*	*	*	*	*	*	*	*
15600	4.31	5.50	6.82	8.18	9.51	10.91	12.37	13.91	15.47	*	*	*	*	*	*	*	*	*
16400	4.89	6.10	7.48	8.89	10.3	11.76	13.25	14.81	16.39	*	*	*	*	*	*	*	*	*
17200	5.51	6.74	8.21	9.67	11.16	12.66	14.15	15.74	17.39	19.10	*	*	*	*	*	*	*	*
18000	6.20	7.48	8.95	10.50	12.07	13.60	15.17	16.80	18.49	20.21	21.98	23.79	*	*	*	*	*	*
18800	6.93	8.29	9.78	11.37	13.02	14.64	16.23	17.88	19.57	21.36	23.20	25.08	26.92	*	*	*	*	*
19600	7.74	9.13	10.65	12.29	13.98	15.68	17.39	19.06	20.84	22.62	24.46	26.41	28.32	30.24	*	*	*	*
20400	8.62	10.05	11.57	13.30	15.03	16.81	18.56	20.30	22.09	23.91	25.83	27.78	29.76	31.75	33.75	*	*	*
21200	9.56	11.05	12.59	14.37	16.14	17.97	19.83	21.65	23.45	25.35	27.20	29.20	31.24	33.30	35.37	37.52	*	*
22000	10.57	12.10	13.70	15.49	17.35	19.21	21.15	22.99	24.93	26.84	28.77	30.71	32.78	34.90	37.04	39.17	*	*
22800	11.64	13.22	14.86	16.68	18.56	20.51	22.51	24.46	26.41	28.39	30.39	32.40	34.42	36.55	38.75	40.95	45.51	*
23600	12.79	14.46	16.14	17.92	19.89	21.87	23.95	25.98	28.01	29.99	32.07	34.15	36.24	38.33	40.61	42.88	47.48	52.09
24400	14.01	15.72	17.44	19.23	21.29	23.34	25.45	27.52	29.68	31.74	33.81	35.97	38.13	40.29	42.43	44.78	49.51	54.24
25200	15.35	17.11	18.86	20.69	22.74	24.82	27.01	29.16	31.41	33.55	35.70	37.85	40.08	42.31	44.52	46.81	51.59	56.46
26000	16.73	18.53	20.36	22.21	24.27	26.43	28.64	30.87	33.13	35.43	37.65	39.88	42.10	44.40	46.69	48.94	53.73	58.73

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B16. Type 16 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
8000	0.95	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9000	1.14	1.99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10000	1.37	2.27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11000	1.62	2.58	3.64	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12000	1.91	2.95	4.05	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13000	2.23	3.35	4.50	5.75	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14000	2.61	3.82	5.01	6.31	7.70	*	*	*	*	*	*	*	*	*	*	*	*	*
15000	3.03	4.29	5.58	6.93	8.37	*	*	*	*	*	*	*	*	*	*	*	*	*
16000	3.52	4.83	6.20	7.61	9.08	10.64	*	*	*	*	*	*	*	*	*	*	*	*
17000	4.06	5.42	6.89	8.37	9.87	11.47	13.14	*	*	*	*	*	*	*	*	*	*	*
18000	4.68	6.06	7.63	9.17	10.72	12.40	14.10	15.90	*	*	*	*	*	*	*	*	*	*
19000	5.33	6.78	8.39	10.02	11.67	13.33	15.16	16.99	18.84	*	*	*	*	*	*	*	*	*
20000	6.08	7.56	9.24	10.97	12.67	14.42	16.21	18.12	20.05	22.05	*	*	*	*	*	*	*	*
21000	6.89	8.39	10.14	11.95	13.77	15.57	17.39	19.30	21.32	23.40	25.47	*	*	*	*	*	*	*
22000	7.77	9.34	11.11	13.02	14.89	16.77	18.69	20.67	22.71	24.80	26.95	29.14	*	*	*	*	*	*
23000	8.73	10.37	12.17	14.10	16.13	18.10	20.05	22.06	24.12	26.26	28.49	30.76	33.06	*	*	*	*	*
24000	9.76	11.46	13.31	15.29	17.37	19.44	21.48	23.58	25.73	27.84	30.08	32.44	34.82	37.12	*	*	*	*
25000	10.87	12.64	14.47	16.61	18.73	20.88	23.04	25.16	27.33	29.53	31.83	34.18	36.64	39.02	41.51	*	*	*
26000	12.11	13.94	15.80	17.94	20.17	22.42	24.61	26.90	29.08	31.37	33.68	36.07	38.53	40.99	43.56	46.12	*	*
27000	13.40	15.28	17.24	19.41	21.68	23.95	26.36	28.63	30.99	33.29	35.69	38.11	40.47	43.13	45.67	48.31	53.66	*
28000	14.82	16.77	18.77	20.89	23.27	25.64	28.07	30.53	32.89	35.28	37.78	40.18	42.68	45.22	47.97	50.58	56.09	61.73
29000	16.29	18.34	20.39	22.51	24.93	27.41	29.95	32.43	34.97	37.35	39.94	42.44	45.03	47.60	50.21	53.03	58.59	64.25
30000	17.91	20.02	22.10	24.29	26.75	29.26	31.81	34.39	37.03	39.61	42.19	44.78	47.34	50.01	52.77	55.44	61.16	66.98
31000	19.58	21.79	23.98	26.20	28.66	31.19	33.85	36.53	39.24	41.95	44.52	47.20	49.86	52.61	55.34	58.15	63.95	69.79
32000	21.41	23.67	25.89	28.21	30.66	33.30	35.97	38.76	41.47	44.27	47.06	49.71	52.59	55.31	58.13	60.89	66.67	72.80

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Table B17. Type 17 Fan Capacity Table

S.P.	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0
CFM	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP	BHP
10000	1.19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11250	1.45	2.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12500	1.74	2.86	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13750	2.07	3.25	4.55	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15000	2.44	3.71	5.08	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16250	2.87	4.25	5.68	7.25	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17500	3.35	4.83	6.35	7.97	9.67	*	*	*	*	*	*	*	*	*	*	*	*	*
18750	3.91	5.47	7.07	8.72	10.50	12.37	*	*	*	*	*	*	*	*	*	*	*	*
20000	4.55	6.17	7.88	9.61	11.42	13.40	*	*	*	*	*	*	*	*	*	*	*	*
21250	5.25	6.92	8.75	10.60	12.46	14.48	16.53	*	*	*	*	*	*	*	*	*	*	*
22500	6.02	7.77	9.71	11.61	13.58	15.62	17.77	19.97	*	*	*	*	*	*	*	*	*	*
23750	6.91	8.70	10.72	12.73	14.76	16.86	19.07	21.37	23.68	*	*	*	*	*	*	*	*	*
25000	7.84	9.69	11.80	13.96	16.08	18.22	20.46	22.84	25.26	27.65	*	*	*	*	*	*	*	*
26250	8.90	10.75	12.95	15.18	17.47	19.73	22.01	24.36	26.90	29.39	31.94	*	*	*	*	*	*	*
27500	10.05	11.99	14.24	16.54	18.94	21.33	23.63	26.10	28.61	31.21	33.85	36.54	*	*	*	*	*	*
28750	11.30	13.31	15.55	17.97	20.45	22.92	25.43	27.92	30.46	33.09	35.84	38.63	41.44	44.39	*	*	*	*
30000	12.65	14.79	17.00	19.57	22.10	24.77	27.31	29.82	32.48	35.17	37.91	40.80	43.72	46.63	49.68	*	*	*
31250	14.10	16.32	18.55	21.18	23.83	26.58	29.29	31.91	34.69	37.38	40.21	43.05	46.07	49.09	52.12	55.23	*	*
32500	15.73	18.02	20.32	22.96	25.66	28.54	31.36	34.10	36.88	39.69	42.63	45.44	48.51	51.64	54.75	57.99	64.34	*
33750	17.40	19.76	22.19	24.84	27.68	30.49	33.46	36.39	39.29	42.21	45.14	48.06	51.10	54.26	57.48	60.83	67.39	*
35000	19.20	21.69	24.17	26.82	29.70	32.75	35.74	38.77	41.80	44.71	47.75	50.78	53.94	57.06	60.30	63.76	70.53	77.40
36250	21.20	23.75	26.27	28.91	31.92	35.00	38.12	41.28	44.42	47.44	50.61	53.76	56.87	60.11	63.29	66.78	73.76	80.84
37500	23.24	25.85	28.49	31.27	34.26	37.36	40.61	43.77	47.06	50.29	53.57	56.68	60.08	63.26	66.55	69.96	77.09	84.17
38750	25.51	28.16	30.94	33.75	36.71	39.95	43.21	46.49	49.91	53.24	56.50	59.88	63.23	66.52	69.93	73.45	80.51	87.81
40000	27.91	30.61	33.42	36.36	39.28	42.65	45.92	49.32	52.88	56.26	59.69	63.20	66.66	70.07	73.60	77.05	84.26	91.54

Note: 1. S.P. (Static Pressure: in H₂O)
2. BHP does not include drive losses

Appendix C: References for Compound Property Data

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