

Thermodynamic Design Of A Condenser Absorption Of Volatile Vapors

Esiquio Martín Gutiérrez Armenta¹, Marco Antonio Gutiérrez Villegas²,
Josué Figueroa González³, Israel Isaac Gutiérrez Villegas^{4,7}, Javier
Norberto Gutiérrez Villegas⁵, Alfonso Jorge Quevedo Martínez⁶.

^{1,2,3}(Departamento de Sistemas, área sistemas computacionales, Universidad Autónoma Metropolitana Unidad Azcapotzalco, México).

^{4,5}(División de Ingeniería en Sistemas Computacionales, TESE- TecNM, México).

⁶(Departamento de Administración, área Matemáticas y Sistemas, Universidad Autónoma Metropolitana Unidad Azcapotzalco, México).

⁷(Departamento de Ingeniería y Ciencias Sociales, Escuela Superior de Física y Matemáticas-IPN, México).

Abstract:

Given the existing losses due to evaporation of any type of fuel as well as the pollution that goes into the environment that many diseases are found with, including the effects on the respiratory system as well as explosions, one of the most dangerous is natural gas, LP, which can be Use the same procedure to design a home or commercial one. This article addresses the problem of gasoline, one of the most dangerous because there is a very large vehicle fleet in our country, Mexico. The storage containers, as well as in its dispatch, produce polluting emissions because gasoline evaporates at approximately twelve degrees Celsius. Other forms of impact are: they go into the atmosphere, land, rainwater, these are harmful to any living being, the environment, finally, they contribute to the greenhouse effect. In this way, the need arises to thermodynamically design a device that prevents the emissions of these gases that in this way condense, recover and avoid economic losses of the business.

Background: A condenser can fall into two categories of cooled or uncooled. Non-refrigerated condensers are widely used as raw material and/or product recovery devices in chemical process industries. They are frequently used before control devices (incinerators or absorbers). Some refrigerated condensers are used as environmental pollution control devices for the treatment of emissions streams with high concentrations of Volatile Organic Compounds.

Materials and Methods: The procedure depends on knowledge of the following parameters: The volumetric flow rate of the gas stream containing Volatile Organic Compound, the inlet temperature of the gas stream, The concentration and composition of the Volatile Organic Compound in the gas stream, The required removal efficiency of the Volatile Organic Compound, Moisture content in the emission stream and The properties of the Volatile Organic Compound (assuming it is a pure compound)

Results: The methodology to be followed is used for any gaseous flow which can be recovered. These calculations can be carried out using a computer, so that the development is not tedious, the prototype remains to be made.

Conclusion: In this research, all the calculations were carried out for the design of a capacitor for any use, only the parameters of what is going to be absorbed must be changed, this can be used as an algorithm to obtain others, because it is necessary to make prototypes that are Adjust to the needs of each company or where you want to implement them, they can also be used in buildings, houses, businesses and in our case in gas stations, in all these places there can be fires due to the accumulation of their evaporation. Energy savings are also contemplated by recovering gases, thereby obtaining more profits for the company, as well as its implementation to avoid contaminating the environment. Finally, it is necessary to develop the prototype by carrying out the necessary tests to know if it meets the requirements.

Key Word: Condensers, Refrigerants, Pollution, Explosion

Date of Submission: 21-10-2023

Date of Acceptance: 31-10-2023

I. Introduction

A condenser can fall into two categories of cooled or uncooled. Non-refrigerated condensers are widely used as raw material and/or product recovery devices in chemical process industries. They are frequently used before control devices (incinerators or absorbers). Some refrigerated condensers are used as environmental

pollution control devices for the treatment of emissions streams with high concentrations of Volatile Organic Compounds, VOC, (typically >5,000 ppmv (parts per million volume)), there are in reality many problems in which these contaminants are found, in this way many applications of this methodology arise, this work is developed for large gasoline terminals which store a large amount of volatile liquid that evaporates at approximately 120C, but in general the changes for any volatile substance, this is limited to the evaluation of refrigerated condensation at constant (atmospheric) pressure for gasoline vapors.

II. Methodology

The procedure for the design (sizing calculation) of refrigerated surface condenser systems to remove the Volatile Organic Compound (VOC) from air/Volatile Organic Compound mixtures is presented. This methodology can be used for any gaseous fluid.

The procedure depends on knowledge of the following parameters:

1. The volumetric flow rate of the gas stream containing Volatile Organic Compound;
 2. The inlet temperature of the gas stream;
 3. The concentration and composition of the Volatile Organic Compound in the gas stream;
 4. The required removal efficiency of the Volatile Organic Compound;
 5. Moisture content in the emission stream; and
 6. The properties of the Volatile Organic Compound (assuming it is a pure compound):
- Heat of condensation,
 - Heat capacity.
 - Vapor pressure.

The design of the refrigerated condenser system requires knowing the size of the Volatile Organic Compound condenser, the refrigeration capacity of the unit. For a given removal efficiency, it is necessary to calculate the condensation temperature and heat load to determine these parameters. The data necessary to perform the calculations with their variables and units are listed in Table no.1.

Table no 1 : Required Entry Data.

Data	Variable Name	Units
Input current ratio	Q_{in}	Ft ³ /(77°F:1atm)
Temperature of the input current	T_{in}	°F
VOC input volume fraction	$Y_{COV,in}$	volume fraction
Required VOC removal efficiency	n	-
Constants of the equation of Antoine	A,B,C	Btu/lb-mole
VOC heat of condensation	deltaH	Btu/lb-mole-°F
VOC heat capacity	$C_{p,COV}$	Btu/lb-°F
Specific heat of coolant	$C_{p,cool}$	Btu/lb-mole-°F
Heat capacity of Air	$C_{p,cool}$	Required Entry Data.

III. Estimation of Condensation Temperature

This calculation is based on the equation¹ which defines the relationship between vapor pressure and temperature ranges (Antoine's equation, Log function base ten).

In his work² consider anesthetic substances to be volatile liquids. Performing calculations for proper regulation, the anesthesiologist requires a simple formula for the expression of the vapor pressure based on temperature, with the ideal pressure the substance can be related to the temperature by:

$$\log_{10} \left(\frac{p_2}{p_1} \right) \frac{\Delta H}{4.57} \left(\frac{1}{t_2} - \frac{1}{t_1} \right) \quad (1)$$

Where ΔH is the latent heat of evaporation (cal mol^{-1}) the temperature at $^{\circ}K$.

The Clausius-Clapeyron equation can be expressed in the form:

$$\log_{10}(P) = A - \frac{B}{T} \quad (2)$$

where A and B are constants, different for each element. This relationship is theoretically reliable only over small temperature intervals. To overcome this limitation, a wide variety of empirical equations have been proposed.

The most useful of these has been³Eq. (3).

$$\log_{10}p^o = A - \frac{B}{T+C} \quad (3)$$

The values for Eq. (3). A, B and C depend on the units used for vapor pressure and temperature. And the range of temperatures at which the correlation was obtained. For the same component, different parameters can be obtained depending on the temperature range. The following figure shows two sets of parameters for calculating the vapor pressure of water for two temperature ranges. Table no.2 shows parameters A, B and C in base ten logarithmic function and in natural logarithm.

Table no 2: Parameters of the Antonine equation [P, mm Hg and [T, °C]

Function	A	B	C	T _{min}	T _{max}
Log10	9.077131	1730.63	233.426	1	100
Ln	18.584881	3984.92	233.426	1	100

The A, B and C, Temperature-dependent vapor pressures are given for nearly 700 important organic chemical compounds. here is provided the maximum and minimum temperatures are symbolized by T_{max} and T_{min}⁴

Reid vapor pressure of 10 and a molecular weight of 66 lb/lb-mole.

$$\begin{aligned} A &= 12.5733 \\ B &= 6386.1 \\ C &= 613 \end{aligned}$$

After substituting these constants in Eq. (3) and assuming an input temperature of 77 ° F (25 ° C) in the Antoine equation and solving by the partial input pressure $P_{COV,in}$ We obtain:

$$\log P_{COV,in} = A - \frac{B}{T_{con} + C} = 12.5733 - \frac{6386.1}{25 + 6134}$$

partial input pressure $P_{COV,in}$ We get:

$$\log P_{COV,in} \approx 366 \text{ mmHg}$$

Volume fractions of VOC in the input and output currents. If the system operates at atmospheric pressure (760 mm Hg), this partial pressure corresponds to the volume fraction of VOC in the input flow

$$\eta = \frac{(760 y_{CON,in} - P_{COV})}{y_{COV,in} (760 - P_{COV})} \quad (4)$$

The partial output pressure ($P_{COV,in}$) and the volume fraction are similarly calculated. The condensation (output) temperature used in these calculations is -80 ° F (62 ° C).

$$\begin{aligned} \log P_{COV,OUT} &= 12.57334 - \frac{6386.1}{-62 + 614} \\ \log P_{COV,OUT} &\approx 9.62 \text{ mm Hg} \end{aligned}$$

This corresponds to the volume fraction in the output flow $y_{cov,out}$ of:

$$y_{cov,out} = \frac{9.62 \text{ mm}}{760 \text{ mm}} = 0.012661007 \approx 0.0127$$

IV. Removal efficiency of the capacitor system (fractional)

The partial output pressure ($P_{COV,out}$) and volume fraction are similarly calculated. The condensation (output) temperature used in these calculations is -80 ° F (-62 ° C).

The removal efficiency of the capacitor system is given by the Eq. (5)

$$\eta = \frac{(760 Y_{COV,in}) - P_{COV}}{y_{COV,in} (760 - P_{COV})} \quad (5)$$

The substitution of $P_{COV,out}$ and $y_{cov,out}$ in Eq. (5) gives the capacitor removal efficiency (η)

$$\eta = \frac{(760 \times 0.482)^{-9.62}}{0.482(760-9.62)} = 0.9862222305733 \approx 0.986$$

This corresponds to the heat load of the Volatil Organic Compound (VOC) capacitor.

The heat load of the capacitor is the amount of heat that must be removed from the input current to obtain the specified removal efficiency. It is determined by an energy balance, taking into account the enthalpy change due to the temperature change of the VOC, the enthalpy change due to the condensation of VOC and the enthalpy change due to the change in air temperature. In the analysis, enthalpy change due to the condensation of VOC, enthalpy change due to the condensation of VOC and enthalpy change due to the change of air temperature. In the analysis, enthalpy change due to the presence of moisture in the inlet gas flow is negligible; it also assumes that the total heat load in the system is equal to the heat load of the VOC capacitor, first the number of lb-moles of VOC per hour in the input current must be calculated by Eq. (6)

$$M_{COV,in} = \frac{Q_{in}}{392 ft^3} (y_{COV,in}) 60 \frac{min}{hr} \quad (6)$$

Where $M_{COV,in}$ is the molar flow ratio of the VOC in the input current, Q is the volumetric flow ratio in $\frac{ft^3}{min}$ (scfm). Factor 392 is the volume ft^3 occupied by a lb-mole of the gas current at normal conditions (77°F to an atmosphere).

Because the velocities of the steam flow of gasoline are typically expressed in gallons/minute must be converted to scfm, pure engines, performs a comparison of this with the cfm of a compressor (The specifications of a CFM air compressor should also include atmospheric pressure, ambient air pressure, temperature and humidity, in order to obtain accurate and comparable figures. The term standard cubic feet per minute (scfm) incorporates these variables. Standard grades. Manufacturers of air compressors calculate the SCFM as CFM at sea level, with an ambient temperature of 68 °F and 36 percent relative humidity. Standard SCFM ratings include a specific pressure, for example, 5.5 SCFM at 90 psi.).

Where $M_{COV,in}$ is the molar flow ratio of the VOC in the input current and Q is the volumetric flow ratio in $\frac{ft^3}{min}$ (scfm). Factor 392 is the volume at ft^3 occupied by an lb-mole of the gas stream entering normal conditions (77°F to an atmosphere). Due to the rate of flow of gasoline vapor are expressed in gallons/minute, scfm must be converted.

$$Q_{in} = Q_g \left(\frac{gal}{min} \right) X \left(\frac{1 ft^3}{7.48 gal} \right) = 0.134 Q_g \text{ scFm}$$

Replacing this value in Eq. (6) results.

$$Q_{in} = Q_g \left(\frac{gal}{min} \right) x \left(\frac{1 ft^3}{7.48 gal} \right) = 0.134 Q_g \text{ scfm}$$

Substituting into Eq. (6). We obtain.

$$M_{COV,in} \approx 0.00989 Q_g \left(\frac{lb - mol}{hr} \right)$$

The number of moles of VOC per hour in the output current must be calculated as follows:

$$M_{COV,out} = M_{COV,in} (1 - \eta) \quad (7)$$

Where $M_{COV,out}$ is the molar flow ratio of VOC at output, then $M_{COV,out}$ is obtained from Eq. (7)

$$M_{COV,out} = 1.38 \times 10^{-4} Q_g \left(\frac{lb - mol}{hr} \right)$$

Finally, the number of lb-moles of VOC per hour that are condensed is calculated as follows.

$$M_{COV,con} = M_{COV,in} - M_{COV,out} \quad (8)$$

Where $M_{COV,con}$ is the flow rate of the VOC is condensed.
According to Eq. (8), it is the amount of condensed gasoline vapour

$$M_{COV,con} = 0.00989Q_g \left(\frac{lb - mol}{hr} \right) - 1.38 \times 10^{-4} Q_g \left(\frac{lb - mol}{hr} \right)$$

$$M_{COV,con} \approx 0.00975 Q_g \left(\frac{lb - mol}{hr} \right)$$

Then the last step is to obtain the heat charge of the capacitor by the Eq. (9)

$$H_{load} = \Delta H_{con} + \Delta H_{un\ con} + \Delta H_{non\ con} \quad (9)$$

Where:

H_{load} capacitor load (Btu/hr)

ΔH_{con} enthalpy change associated with condensed VOC (Btu/hr)

$\Delta H_{un\ con}$ enthalpy change of non-condensed VOC (Btu/hr)

$\Delta H_{non\ con}$ enthalpy change associated with non-condensable air (Btu/hr).

The enthalpy change in condensed VOC is calculated as follows:

$$\Delta H_{con} = M_{COV,con} + C_{p,COV} (T_{in} - T_{con}) \quad (10)$$

Where ΔH_{con} is the molar heat of condensation and $C_{p,COV}$ are evaluated at the average temperature.

$$T_{mean} = \frac{T_{in} - T_{con}}{2} \quad (11)$$

The enthalpy change associated with the non-condensed VOC is calculated by Eq.(12).

$$\Delta H_{con} = M_{COV,out} C_{p,COV} (T_{in} - T_{con}) \quad (12)$$

Finally, the enthalpy change of non-condensable air is calculated by Eq. (13).

$$\Delta H_{mom,com} = \left[\frac{Q_{in}}{392ft^3} \times 60 \frac{min}{hr} - M_{COV,int} \right] C_{p,air} (T_{in} - T_{con}) \quad (13)$$

Where $C_{p,air}$ is the specific heat of air, in Eq. (10), Eq. (13), the C_{pS} are evaluated at the mean temperature, as in Eq. (11), therefore, the VOC heat capacity and heat of condensation data used are based on the chemical properties of butane and pentane, the major components of gasoline, these were obtained from the risk manual data⁵.

Units of heat capacity are given in (Btu/lb-mole-°F):

$$C_{p,COV} = 26.6$$

$$C_{p,air} = 6.95$$

The heat of condensation of VOC is 9,240 Btu/lb-mole.

By substituting this information into Eq. (13) the following enthalpy changes are obtained.

$$\Delta H_{con} = M_{COV,con} \left(\Delta H_{COV} + C_{p,COV} (T_m - T_{con}) \right) \quad (14)$$

$$\Delta H_{con} = (0.00975 Q_g) M_{COV,con} \left(9240 + 26.6(77 - (-80)) \right)$$

$$\Delta H_{con} = 130.80795 Q_g \approx 130.8 Q_g$$

$$\Delta H_{un\ con} = (1.38 \times 10^{-4} Q_g) (26.6)(77 - (-80))$$

$$\Delta H_{un\ con} \approx 0.572 Q_g \quad (\text{Btu/hr})$$

$$\Delta H_{con} = M_{COV,con} \left(\Delta H_{COV} + C_{p,COV} (T_m - T_{con}) \right) \quad (15)$$

$$\Delta H_{nom\ con} = \left[\left(\frac{Q_{in}}{392ft^3} 60 \frac{min}{hr} \right) - M_{COV,in} \right] C_{p,air} (T_{in} - T_{con}) \quad (16)$$

$$\Delta H_{nom\ con} = \left[\left(\frac{Q_{in}}{392ft^3} 60 \frac{min}{hr} \right) [1 - y_{con,in}] \right] C_{p,air} (T_{in} - T_{con})$$

$$\Delta H_{nom\ con} = \left[\left(\frac{Q_{in}}{392ft^3} 60 \frac{min}{hr} \right) [1 - 0.482] \right] 6.95(77 - (-80))$$

$$\Delta H_{nom\ con} = 865126893571(0.134 Q_{in}) \approx 11.6 Q_g \left(\frac{btu}{hr} \right)$$

$$\Delta H_{nom\ con} = 865126893571(0.134 Q_m)$$

The capacitor load (H_{load}) will be the sum of these three enthalpy changes Eq. (9)

$$\Delta H_{load} = 130.8 Q_g + 0.572 Q_g + 11.6 Q_g \approx 143 Q_g \left(\frac{btu}{hr} \right)$$

To obtain the refrigeration capacity, it is assumed that the refrigeration unit will provide the refrigerant to the condenser, at the required temperature, this is required and is expressed in terms of tons of refrigerant that is obtained using Eq. (17)

$$R = \frac{H_{load}}{12000} \quad (17)$$

Where H_{load} does not include any heat loss, substituting this in Eq.(17)

$$R = \frac{H_{load}}{12000} = \frac{143 Q_g}{12000} = 0.0119166667 Q_g \approx 0.0119 Q_g$$

$$R \approx 0.0119 Q_g$$

This last value relates the cooling capacity (tons) to the inlet gasoline vapor flow rate (gal/min). solving for Q_g we obtain:

$$Q_g = 83.9 R$$

Condenser sizes are designed based on the heat load, the logarithmic measure of the temperature difference between the refrigerant emission streams, and the total heat transfer coefficient. This total heat transfer coefficient U can be estimated from the individual heat transfer coefficients of the gas and refrigerant streams. This total heat transfer coefficient for tubular heat exchangers, where organic solvent vapors in non-condensable gas condense on the shell side, water/brine circulates on the tube side, their typical values vary from⁶ in 20 to 60 Btu/hr-ft² -°F, for a simplification of calculations a value of U can be used, for the design of these, therefore, an estimate of 20 Btu/hr-ft² -°F to obtain a size calculation given by Eq.(17), to determine the area required for heat transfer:

$$A_{con} = \frac{H_{load}}{U \Delta T_{lm}} \quad (18)$$

Where:

A_{con} capacitor surface area (ft²)

U overall heat transfer coefficient (btu/hr-(ft²)- °F)

T_{lm} logarithmic mean of the temperature difference (°F), the logarithmic mean of the temperature difference is calculated by Eq. (19), which is based on the use of the current flow capacitor:

$$\Delta T_{lm} = \frac{(T_{in} - T_{cool,out}) - (T_{con} - T_{cool,in})}{\ln \left(\frac{(T_{in} - T_{cool,out})}{(T_{con} - T_{cool,in})} \right)} \quad (19)$$

Where:

$T_{cool,in}$ coolant inlet temperature (°F)

$T_{cool,out}$ coolant outlet temperature (°F)

An assumption is made that the temperature differences (“approximation”) at the condenser outlet are 15°F lower than the calculated condensation temperature T_{con} . Also the increase in refrigerant temperature reflects a good design practice that is used. It results from an acceptable size of the capacitor, therefore, Eqs. (20), and Eq. (21), are applied to determine the inlet and outlet temperatures of the coolant.

$$T_{cool,in} = T_{con} - 15 \text{ }^{\circ}\text{F} \quad (20)$$

$$T_{cool,out} = T_{cool,in} + 25 \text{ }^{\circ}\text{F} \quad (21)$$

The temperature difference (“approach”) at the condenser outlet is assumed to be 15 oF, in other words, the refrigerant inlet temperature $T_{cool,in}$ is 15 °F, less than the calculated condensation temperature T_{con} also, the increase in temperature of the refrigerant, reflects a good design calculation, this will result from an adequate size of the condenser.

Therefore, Eqs. (20), Eq. (21) are used to determine the inlet and outlet temperatures.

So, to determine the size of the condenser, logarithmic measurements of the temperature differences must be determined.

$$\begin{aligned} \Delta T_{cool,in} &= -96 \text{ }^{\circ}\text{F} \\ \Delta T_{cool,out} &= -70 \text{ }^{\circ}\text{F} \end{aligned}$$

$$\Delta T_{lm} \approx 57.834$$

The capacity of a refrigeration unit is the rate at which heat is removed, expressed in tons of refrigeration. One ton of this is the refrigeration produced by melting one ton of ice at 32°F in 24 hours. This is the heat removal rate equivalent to 12,000 btu/hr or 200 Btu/min.

To carry out the calculation, a ratio of $U=20$ Btu/hr- ft²-°F is used as the overall heat transfer coefficient.

$$A_{con} = \frac{H_{load}}{U\Delta T_{lm}} = \frac{143Q_g}{(20)(57.834)} \approx 0.124Q_g ft^2 \quad (22)$$

The coolant flow rate. The heat removed from the emission stream is transferred to the refrigerant, performing an energy balance, the refrigerant flow rate can be calculated as:

$$W_{cool} = \frac{H_{load}}{C_{p,cool} (T_{cool,out} - T_{cool,in})} \quad (23)$$

Where W_{cool} is the refrigerant flow rate (lb/hr) and $C_{p,cool}$ is the specific heat of the refrigerant (Btu/lb-°F), $C_{p,cool}$ will vary according to the type of refrigerant used. The specific heat of brine (salt water), another commonly used refrigerant, is approximately 1.0 Btu/lb-°F.

$$C_{p,cool} = 1.0 \text{ Btu/lb-}^{\circ}\text{F}$$

$$W_{cool} = \frac{143Q_g}{(1.0)} [-70 F - (-95F)] = 5.72Q_g \text{ lb/hr}$$

The mass of the volatile organic compound recovered in the condenser can be calculated using the following Eq.(21).

$$W_{COV,con} = W_{cool} X MW_{COV} \quad (24)$$

Where:

$W_{COV,con}$ mass of Volatile organic compound recovered (or condensed) (lb/hr)

MW_{COV} molecular weight of the Volatile organic compound (lb/lb-mole) can also be determined from these from gas chromatometry retention data using the work Michal Hoskovec, et al.(2005).

$$W_{COV,con} \approx 0.00975Q_g \left(\frac{\text{lb-mole}}{\text{hr}} \right) \text{ the molecular weight } MW_{COV} = 66 \frac{\text{lb}}{\text{lb-mole}} \text{ - mole in this way we have:}$$

$$W_{COV,con} = 0.00975Q_g X 66 = 0.6435Q_g$$

$$W_{COV,con} \approx 0.644Q_g \left(\frac{\text{lb}}{\text{hr}} \right) \text{ Cov recovered.}$$

V. Results and Discussion

The methodology to be followed is used for any gaseous flow which can be recovered. These calculations can be carried out using a computer, so that the development is not tedious, the prototype remains to be made.

VI. Conclusion

In this research, all the calculations were carried out for the design of a capacitor for any use, only the parameters of what is going to be absorbed must be changed, this can be used as an algorithm to obtain others, because it is necessary to make prototypes that are Adjust to the needs of each company or where you want to implement them, they can also be used in buildings, houses, businesses and in our case in gas stations, in all these places there can be fires due to the accumulation of their evaporation. Energy savings are also contemplated by recovering gases, thereby obtaining more profits for the company, as well as its implementation to avoid contaminating the environment. Finally, it is necessary to develop the prototype by carrying out the necessary tests to know if it meets the requirements.

References

- [1]. Chemical Hazard Response Information System (CHRIS) Hazardous Chemical Data (Ref. 3-29) COMDTINST M16565.12C Is Available Online At [Www.Chrismanual.Com](http://www.chrismanual.com). Reactivity Group, Water Reactivity, And Reactivity With Common Materials Are Given, As Well As Bulk Cargo Compatibility Matrix
- [2]. Hoskovec, M., Grygarová, D., Cvačka, J., Streinz, L., Zima, J., Verevkin, S. P., & Koutek, B. (2005). Determining The Vapour Pressures Of Plant Volatiles From Gas Chromatographic Retention Data. *Journal Of Chromatography A*, 1083(1-2), 161-172. <https://doi.org/10.1016/j.chroma.2005.06.006>
- [3]. Perry, R. H., & Green, D. W. (2008). *Perry's Chemical Engineers' Handbook*, Eighth Edition. MCGRAWHILL.
- [4]. Rodgers, R., & Hill, G. (1978). Equations For Vapour Pressure Versus Temperature: Derivation And Use Of The Antoine Equation On A Hand-Held Programmable Calculator. *British Journal Of Anaesthesia*, 50(5), 415-424. <https://doi.org/10.1093/bja/50.5.415>
- [5]. Yaws, C. L., & Yang, H. C. (1989). To Estimate Vapor Pressure Easily. OSTI.GOV Title Logo. <https://www.osti.gov/biblio/5296397>