Calculation of Vacuum Pump Sucking Rate in Fishing Suction Equipment of Trawler

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Abstracts. Sucking rate is an important parameter for the design of vacuum pump, in order to obtain the accurate sucking value. Above all, sucking process of vacuum-pump is analyzed in fishing suction equipment, and then by means of Boyle-Malot's law, a new equation is deduced, and a new method is improved after analyzing calculation formulas about sucking rate of vacuum-pump at the present time, this paper provides basis for selecting and design vacuum-pump in fishing suction equipment. After using the new formula to calculate the sucking rate, the damage rate of fish is greatly reduced in fishing suction.

Keywords: Fishing suction equipment; Trawler; Vacuum pump; Sucking rate.

1. Introduction
In the design of fishing suction device of trawler, it is very important to choose the calculation method of vacuum pump suction rate. At present, there are several methods to calculate the sucking rate, for the same device, in the same operating state, the results obtained by several methods of sucking rate are quite different. This calculation results bring great trouble to the choice of vacuum pump. In this paper, based on the analysis of the existing formula, according to the actual pumping process of the vacuum pump, with the help of Boyle-Malot's law, a new calculation formula is deduced, and a new vacuum pump selection method is raised, it provides an important basis for the selection and design of vacuum pump for fishing suction device of trawler.

2. Calculation Method of Original Sucking Rate
According to literature[1],[2],[3], when vacuum pump is used to sucking gas, there are three calculation methods to select vacuum pump.

2.1. The Turk Formula

\[ Q_a = \frac{(V_1 + V_2)H_1}{T(H_1 - H_s)} k \]  

Here, \( Q_a \) is average sucking rate, m³/min, \( V_1 \) is volume of pipes, m³, \( V_2 \) is empty volume in pump case, m³, \( H_1 \) is the height of the water column at atmospheric pressure, the general value is 10m, \( H_s \) is pump suction height, m; \( T \) is sucking time, min, \( k \) is reserve factor, the general value is 1.1.
2.2. Special Water Formula

\[ Q_a = 2.3k \frac{V_1 + V_2}{TZ} \lg \frac{H_1}{H_1 - H_g - \Delta h} \]  \hspace{1cm} (2)

Here, \( Z \) is number of pumps, \( \Delta h \) is distance from the centre line of the pump case to the ground, m.

Average vacuum degree for pumping \( H_v \) as follows.

\[ H_v = \frac{(H_g + \Delta h)}{2} \]

2.3. Formula Recommended in the Water Supply and Drainage Design Handbook

\[ Q_a = \frac{V_1 + V_2}{T} k \]  \hspace{1cm} (3)

By analyzing formulas (1),(2) and (3), the following problems can be found.

(1) The above three calculation methods ignore the influence of pipeline layout and section shape on the calculation results. If the required vacuum is assumed to be equal to the total volume of gas in the pipeline and the fish tank, according to the above formulas, the calculated sucking rate is equal, this is clearly inconsistent with the actual situation, because the sucking rate of the vacuum pump is different between high vacuum and low vacuum, the actual pumping time is also different.

(2) Vacuum pump sucking process is a continuous process of change, formula (1) only considers the suction of all gases in a high vacuum state, so that the calculated sucking rate is much larger than the actual requirement.

(3) Formula (2) is deduced under the condition of vacuum in a closed container, without considering the change of gas volume caused by the continuous filling of water in the pipeline, the calculation results will be very wrong, Therefore, it is not appropriate to use it in the vacuum calculation of fish suction device.

(4) Formula (3) does not consider the effect of vacuum on unit gas extraction, which is theoretically not allowed.

3. New Calculation Method

The suction process of vacuum pump can be approximated as isothermal process, when sucking, the pressure and volume are variables, and the pressure \( P_{n-1} \) must be corresponding to a volume \( V_{n-1} \) at a certain time.

\[ V_{n-1} = V_1 - \left( \frac{p_1 - p_{n-1}}{\gamma} \right) s = V_1 - \frac{p_1 - p_{n-1}}{\gamma} s \]  \hspace{1cm} (4)

Here, \( s \) is cross-sectional area of pipe, m², \( p_1 \) is atmospheric pressure, kg/m³, \( \gamma \) is density of water, kg/m³.

If the gas flow be sucked is \( \Delta V \) in the tube, the pressure in the tube is reduced from \( p_{n-1} \) to \( p_n \), Lower pressure will cause the water in the tube to rise by a micro-volume \( dV \), here, \( dV = s \frac{dp}{\gamma} \). At this point, the volume corresponding to the pressure \( p_n \) are as follows.

\[ V_n = V_{n-1} + \Delta V - dV = V_1 - \frac{p_1 - p_{n-1}}{\gamma} s + \Delta V - s \frac{dp}{\gamma} \]  \hspace{1cm} (5)

According to Boyle-Malot's law, there are as follows.
By substituting formula (4) and formula (5) into formula (6), there are as follows.

\[ p_n (V_1 - \frac{p_1 - p_{n-1}}{\gamma} s + \Delta V - s \frac{dp}{\gamma}) = p_{n-1} \left( V_1 - \frac{p_1 - p_{n-1}}{\gamma} s \right) \]  

(7)

Simplify and expand formula (7), there are as follows.

\[ \Delta V = (V_1 - s \frac{p_1}{\gamma}) \frac{dp}{p_n} + \frac{p_n}{\gamma} \frac{dp}{p_n} + s \frac{dp^2}{\gamma} + \frac{s}{\gamma} dp \]  

(8)

\[ \frac{s}{\gamma} \frac{dp^2}{p_n} \] is leaved out in formula (8), it is as follow.

\[ \Delta V = (V_1 - s \frac{p_1}{\gamma}) \frac{dp}{p_n} + 2 \frac{s}{\gamma} dp \]  

(9)

Assuming that the Q is the volume of gas passing through the inlet section per unit time, volume of gas pumped by vacuum pump is \( Q \cdot dT \), because \( Q \cdot dT \) is equal to \( \Delta V \), there are as follows.

\[ QdT = -\Delta V = - \left[ \left( V_1 - s \frac{p_1}{\gamma} \right) \frac{dp}{p_n} + 2 \frac{s}{\gamma} dp \right] \]  

(10)

The two ends of formula (10) are integrated separately, and the initial pressure \( p_1 \) and the pressure \( p_2 \) after T are substituted into as follows.

\[ \int_0^T QdT = \int_0^T \left[ \left( V_1 - s \frac{p_1}{\gamma} \right) \frac{dp}{p_n} + 2 \frac{s}{\gamma} \times dp \right] \]  

(11)

Formula (11) is integrated, there are follows.

\[ QT = \left( V_1 - s \frac{p_1}{\gamma} \right) \ln \frac{p_2}{p_1} + 2 \frac{s}{\gamma} (p_1 - p_2) \]  

(12)

Dividing formula (12) by T.

\[ Q = \frac{\left( V_1 - s \frac{p_1}{\gamma} \right) \ln \frac{p_2}{p_1} + 2 \frac{s}{\gamma} (p_1 - p_2)}{T} \]  

(13)

\[ \frac{p_1}{\gamma} = H_1, \quad \frac{p_2}{\gamma} = H_2 \]  

(14)

Here, \( H_1 \) is atmospheric pressure water column high, the general value is 10m, \( H_2 \) is \( p_2 \) High pressure water column, m.

Substitute formula (14) int0 formula (13).
Average pressure $H_{pj}$ in tube is as follow.

$$H_{pj} = H_1 - \frac{H_p}{2}$$  \hspace{1cm} (16)

Because the Q decreases with the pressure, the unit sucking rate of the vacuum pump is expressed as the average, then according to the gas volume Q and the average pressure $H_{pj}$ in the pipe, the main parameters of the vacuum pump are selected. The newly deduced formula can be expressed by subsection calculation.

$$W = QT = \left[ (V_1 - s_1 H_1) \ln \frac{H_1}{H_2} + 2s_1(H_1 - H_2) \right] k + \left[ (V_2 - s_2 H_2) \ln \frac{H_2}{H_3} + 2s_2(H_2 - H_3) \right] k + ...$$  \hspace{1cm} (17)

Here, $W$ is total sucking rate, The average sucking rate is as follow.

$$Q_a = \frac{W}{T}$$  \hspace{1cm} (18)

$$H_{pj} = H_1 - \frac{H_{gn}}{2} \hspace{1cm} n = 1, 2, ...$$  \hspace{1cm} (19)

$Q_a$ and $H_{pj}$ can be used as selecting primary vacuum pump parameters, and the following formula can be used to check whether the suction time is appropriate.

$$T_1 = \left[ (V_1 - s_1 H_1) \ln \frac{H_1}{H_2} + 2s_1(H_1 - H_2) \right] \frac{k}{Q_1} ;$$

$$T_2 = \left[ (V_2 - s_2 H_2) \ln \frac{H_2}{H_3} + 2s_2(H_2 - H_3) \right] \frac{k}{Q_2}$$

......

(20)

Here, $Q_{a1}$, $Q_{a2}$, ...., $H_{pj1} = H_1 - \frac{H_{g1}}{2}$, $H_{pj2} = H_1 - \frac{H_{g2}}{2}$, ...., these parameters can be obtained from the sample parameters of the vacuum pump.

It should be noted that if the suction tube of the vacuum pump is very long or the speed of the suction tube is very large, the loss of pressure in the tube is considered.

$$H_{pj} = H_1 - \frac{H_{gn}}{2} - \Delta h$$  \hspace{1cm} (21)

Here, $\Delta h$ is pressure loss of suction tube.

If the pressure loss of the suction tube is small, it can be ignored.

4. Conclusion

Using the newly derived formula, the extraction capacity of the vacuum pump of the fish suction device is calculated and selected, the designed vacuum system can meet the actual needs of fish
suction production and obtain satisfactory results, after using the new method to calculate the sucking rate, the damage rate of fish is greatly reduced in fishing suction.

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