Novel Pneumatic System for Lime Dosage in Water Treatment Application

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Abstract. This paper proposes a new pneumatic mechanism for lime dosage in water treatment application. Conventionally, current water treatment system technologies utilising pump system, which requires scheduling maintenance of operation to avoid choke problem due to scaling development. The choke formation depends on the lime dosage concentration, which will be based on the time of operations. Technically, the pneumatic system uses such a hydraulic mechanism consisting of fluid, especially liquid oil, to operate, requiring higher maintenance costs. Based on these arguments, this research investigates the potential of replacing the pump system with an air pneumatic system for water treatment. For that reason, this study proposed a new design of pneumatic mechanism as the alternative solution for pump system. Several analyses have been performed from fluid mechanics to study the water treatment plant flow rate that could be competitive with the conventional pump system.

1. Introduction

Water treatment intensifies water quality to adhere to the water quality standards for its sustainability for the intended usage after being chemically or biologically contaminated. Commonly, it is understood that untreated water is significant intimidation to individual either human or animals well-being, industrial processes, as thoroughly as the environment. For some reason, treated water saves industrial facilities, and water supply wares from corrosion. For example, microplastic (MPs) appears as one of the pollutants in the aquatic environments [1], as the waste produced by the industries widely that would harm the society due to the absorbance of a few hazardous inorganic chemical substances in the water [2].

Precisely, lime is classified as an inorganic modifier due to its prominent role in modifying the pH measurement. It is known that the flotation reaction of sulphide minerals and their synergies with receivers (xanthates, dithiophosphates, thionocarbamates, and their derivates) is greatly pH-dependent [3]. In Malaysia, lime is considered as most common reagent used in the extractive minerals [4] that consists of calcium oxide or calcium hydroxide at most of the water treatment plants.

Most of the current water treatment plants utilised the pump system as the mechanical devices that could transfer the mixture between lime and untreated water from the mixture tank. For some reason, several innovations such as pump diffusion flash mixing (PDFM) for enhancing concentration process in drinking water treatment as made by Kim and Lee [5] where they proposed a relevant system for coagulant dosage optimisation.
However, due to limescale issues [6-7] as shown in figure 1. and cavitation development [8-9] in most pump system components; tube or pipe, the water treatment plants require frequent maintenance scheduling that could lead to higher operations costs to sustain the dosing flow rate will cause the choke problem in the water flow and will reduce the dosing flow rate, while the pressure needed is increased. To counter this issue, the pneumatic system would be a great solution since the history of reliable mechanism have been discovered in some applications such as reduction of ballast tank sediment [10], aeronautical landing gear systems [11-12] and multi-pipe drilling technology [13].

![Figure 1. Developed scaling in common pump systems in such pipe or tube components.](image)

For that reason, this research proposes a novel pneumatic mechanism that composes of the two-cylinder column as the replacement for the pump system by utilising the air as the medium of transferring the water treatment mixture. The analysis comprises several views from the fluid flow assessment and the dosing rate as a reliable option to the conventional pump system.

2. Pneumatic mechanical design

2.1 Design requirements and objective

In this study, the design requirements and objective relies on designing a novel efficiency pneumatic system that would be reliable compared to the existing conventional pump system in water treatment application. To achieve this, several analyses such as flow rate assessment and the dosing rate assessment are conducted.

2.1.1 Flow rate measurement

In this research, the flow rate measurement is crucial in determining the desired lime dosing rate that would be the core element in designing the pneumatic system. In that case, the calculation on pressure changes are required to measure the flow rate since the pneumatic system is integrated between the several components; such as air compressor, 2x column cylinders and indicator needle valve. In this project, the control needle valve is applied to control air flow.

The flow rate, \(Q\) is measured as the inlet airflow speed, \(v_1\) at the inlet, opening throat area multiplied with \(A_1\) which is equivalent as the outlet water flow \(v_2\) multiplied with the outlet throat area, \(A_2\) as shown in equation 1.

\[
Q = v_1A_1 = v_2A_2
\] (1)

As mentioned earlier that the control needle valve is utilised in controlling the airflow, the inlet and outlet speed would be translated to the changes of pressure as in equation 2.
Later, equations 1 and 2 are combined in the sense of the relation with these parameters as in equation 3.

$$P_1 - P_2 = (v_2^2 - v_1^2)$$  \hspace{1cm} (2)

$$Q = A_1 \frac{2}{\rho} \left( \frac{p_1 - p_2}{A_2} \right) - 1 = A_2 \frac{2}{\rho} \left( \frac{p_1 - p_2}{A_1} \right) - 1$$  \hspace{1cm} (3)

From the flow rate, Q can be plotted on a graph flow rate verses time in this research experiment to know the dosing per time and the effectiveness of this pneumatic lime dosing system by using pneumatic method comparing to metering pump system.

2.1.2 Dosing rate measurement

In addition, the dosing calculation also one of important element to be considered since the particle of chemical would be relies on this relationship. The dosing rate is measured as in Equation 4, where the particle per minute, PPM depends on the rate of induced particle and the concentration of the mixture between lime and water, C. For instance, the pneumatic cylinder air flow that can be related to the flow rate, Q as in Equation 4.

$$D = \frac{Q \times \text{PPM} \times 100}{1000 \times C}$$  \hspace{1cm} (4)

To summarize, several components are essential in assessing the dosing rate measurement in presented in table 1.

**Table 1.** Summary on components and control parameters utilised in this study.

| Type of cylinder       | Components                                      | Control Parameters      |
|------------------------|-------------------------------------------------|-------------------------|
| Double acting cylinders| • Piston Area (Bore x 3.1415)                   | • Stroke                |
|                        | • Road Area (for double-acting cylinders)       | • Cycles per minutes    |

For a single-acting cylinder, the air consumption that is used in inducing the pressure as in Cubic feet per minute is as in equation 5, where A is the piston area, S is the applied stroke, and C is the cycles per minute.

$$CFM = \frac{A \times S \times C}{1728}$$  \hspace{1cm} (5)

Since this study uses double-acting of air consumption, hence the relationship of the parameters should be modified. In specific applications, the double-acting cylinder may be required to extend and retract at a different rate. On that matter, the condition changes the consideration of air consumption. In this situation, the air consumption of each stroke could be calculated separately as in equation 6, where EC is the extend cycles per minute (ignoring dwell time) and RC is the retract cycles per minute (ignoring dwell time).

$$CFM = \frac{A \times S \times EC}{1728} + [(A - R) \times S \times RC]$$  \hspace{1cm} (6)
The pneumatic system will utilise air compression mechanism in order to execute the kinematic motion of two designed calibration columns unit. The expected results will comprise the dosing rate compression efficiency throughout the mechanical system. The schematic diagram is demonstrated as in figure 2.

![Diagram of the design pneumatic system fluid flow transfer.](image)

Figure 2. Diagram of the design pneumatic system fluid flow transfer.

2.2 Prototype fabrication

Figure 3 describes the fabricated prototype of the designed water treatment plant using an advanced pneumatic system. This system contains equipment that plays a vital role in carrying the dosing in preparation tank to dosing point. It works differently as a pump but purely used by pneumatic air as energy transfer. Therefore, this system's critical equipment such as pneumatic column, solenoid valve, and air regulator controls the airflow as an energy force to carry the dosage. Moreover, this system uses a rotameter calibration flow for calibrating dosing. From the data rotameter calibration, it can gather the total dosing flow that carrier to dosing point.

![Developed pneumatic system prototype for the water treatment plant.](image)

Figure 3. Developed pneumatic system prototype for the water treatment plant.
3. Results and discussions
The developed prototype is being assessed with the consideration of having such competitive performance with the conventional pump system in water treatment. For instance, the pneumatic system is tested before it could be commissioned and been manufactured into the market.

3.1 Dosing rate assessment
The measurement of dosing rate for this water treatment system is obtained via the reading taken at the rotameter as the mixture of water and lime is flowing as demonstrated in figure 4. Figure 4 shows the pressure gauge reading via the rotameter flow when the pressure increases by adjusting the air regulator.

The rotameter dosing flow increases based on air energy that forces the dosage to dosing point. Figure 5 presents the dosing rate graph versus pressure to compare percentage opening on needle inlet air at air regulator outlet.

![Figure 4. Dosing rate measurement via rotameter](image)

![Figure 5. Comparison of the obtained dosing rate at several percentage of opening valve for several applied pressure.](image)
4. Conclusion
This research intends to design an advanced pneumatic system for water treatment application. In this project, the result of run test dosing rate with different pressure such that from 10 MPa to 60 MPa and different opening areas for air outlet opening needle valve (10%, 20% and 30%) applied on this system pneumatic dosing shown that the dosing rate will increase when the pressure and air outlet opening on needle valve increase.

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