CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results and data analysis of the pump-valve system regarding the water hammer phenomenon, several conclusions can be drawn as follows:

1. Valve-closure time has the most significant influence on the magnitude of water hammer pressure. The faster the valve is closed, the higher the peak pressure produced. For example, at a flowrate of 38,67 L/min with a closure time of 1 second, the peak pressure reached 1,61 bar, whereas at closure times of 1,5 seconds and 2 seconds, the peak pressure decreased to 1,31 bar and 1,13 bar, respectively. The statistical result shows a p-value of $4{,}36\times10^{-7}$ with a negative coefficient of -0,2697, indicating a strongly significant influence, where a smaller closure time yields a more significant effect.
2. Flowrate is directly proportional to water hammer pressure. A higher flowrate increases fluid velocity and kinetic energy, resulting in a higher pressure surge when the valve is closed. At a flowrate of 38,67 L/min, the maximum experimental pressure reached 1,61 bar, while at flowrates of 33,26 L/min and 26,61 L/min, the peak pressures decreased to 1,34 bar and 1,04 bar, respectively. The statistical analysis yielded a p-value of $2{,}85\times10^{-5}$ with a positive coefficient of 0,0198, indicating a significant influence, although still lower compared to valve-closure time. The positive coefficient means that increasing the flowrate results in a more significant pressure rise.
3. The effective head shows a positive but statistically less significant relationship with water hammer pressure. With a p-value of 0,1206, its influence is weaker than those of the two previous variables. An increase in effective head, obtained from the sum of static and dynamic head, contributes to higher total system pressure. Theoretically (for instantaneous closure), at the highest flowrate of 38,67 L/min, the effective head reaches 8,7836 m with a theoretical peak pressure of 5,861 bar, while at the lowest flowrate of 26,61 L/min, the effective head decreases to 7,8606 m with a corresponding pressure of 4,046 bar.

5.2 Recommendations

For future research developments and improvements to the pump–valve experimental system, the following recommendations are proposed:

1. Expand the analysis of effective head to determine cavitation parameters more accurately.
2. Use pumps with higher capacity and efficiency to ensure more stable and measurable system pressure.
3. Add a motor speed controller (inverter or VFD) to maintain stable flowrate and minimize pressure fluctuations.
4. Integrate an actuator controlled by Arduino or PLC so that valve-closure time can be digitally programmed with consistent timing, eliminating operator-induced variability.
5. Use higher-pressure-class piping materials (such as HDPE PN10 or higher) to withstand greater pressure loads.
6. Replace PVC adhesive joints with threaded or compression fittings to prevent leakage under high pressure.
7. Redesign the piping layout to reduce the number of elbows, which contribute significantly to minor losses.