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Prototype of Laminer and Turbulent Flow Learning Tools in the Fluid Mechanics Course at the Mechanical Engineering Study Program, Faculty of Engineering, Universitas Negeri Manado

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ABSTRACT

In this study, the aim is to develop and analyze the performance of prototype laminar and turbulent flow learning tools in the Fluid Mechanics course in the Mechanical Engineering Study Program. The development of the tool was carried out to make it easier for students to understand the differences in flow characteristics through direct observation of changes in discharge, flow velocity, and Reynolds numbers. The research method used was an experiment by measuring discharge between 0.5–2 L/s on a transparent pipe with a diameter of 20 mm. Flow rate data is calculated based on actual discharge, while pressure is measured using differential manometers. Furthermore, the data were analyzed using the Reynolds number equation and the pressure loss theory (Darcy–Weisbach). Overall, the results show that the prototype is able to show the flow transition clearly, with the critical limit of the flow being at the average Reynolds number of about 2,200. At low discharge, the flow pattern indicates the stability of the laminar flow, while at high discharge vortex and velocity fluctuations are formed that mark turbulent flows. Pressure loss measurements also show a linear increase in laminar flow and a non-linear increase in turbulent flow, in line with fluid theory. These findings prove that the prototype developed is effective as a learning medium because it is able to visualize changes in flow regimes in real-time and provide a more interactive practicum experience.

Keywords: fluid mechanics, laminar flow, learning prototype, reynolds number, turbulent flow.

INTRODUCTION

The Fluid Mechanics course is an important course for Mechanical Engineering students. An understanding of fluid flow, both laminer and turbulent, is an important foundation in a wide range of engineering applications, such as piping system design, aerodynamics, and turbines. However, the concept of laminer and turbulent flows is often difficult for students to understand. This is due to the abstract nature of the concept which is difficult to visualize and understand directly through theory alone. Fluid flow is very common in our daily lives. One example is the flow of water in a ditch, the flow of water in the river, the flow of air, and many more. Dayana, I., & Marbun, J. (2024) said that fluid mechanics is a branch of mechanics that studies the movement of fluids. The movement is observed in the form of liquid or in the form of gas. Fluid mechanics also studies fluids that are not in a moving or stationary state.

The Mechanical Engineering study program, Faculty of Engineering, Manado State University, in this case there are still limitations in fluid mechanics laboratory facilities which is one of the obstacles in the learning process. With the creation of this prototype, it is hoped that students can gain direct experience in analyzing the flow of laminar and turbelen. According to Tanahitumessing F (2022:45-52), praktikum as a form of direct learning is an absolute thing for students of the Faculty of Engineering. Through practicum, students can get to know more closely and apply the theories that have been obtained. To overcome these obstacles, learning aids are needed that can help students visualize and understand the concepts of laminer and turbulent flows more easily. The development of prototypes of this learning tool is very much needed in the teaching and learning process. Suryanto, I. A. (2023), said that to facilitate the solution and writing of various conditions and problems in Fluid Mechanics. Mathematical Models are used. The most fundamental mathematical models in Fluid Mechanics use Partial Differential Equations, such as the Navier-Stokes Equation, the Continuity Equation, etc. After getting the equation in the analysis of the flow of 2 fluids, what must be carried out is to solve the problem or find a solution (Problem Solving) to the problem.

There are three types of fluid flows: laminar, transitional, and turbulent. identify flows in pipes by using the Reynolds Number equation. To obtain it must determine the discharge, flow velocity, pipe diameter, and kinematic viscosity of the fluid (a measure of the viscosity of the fluid). Fluids are substances that cannot withstand permanent changes in shape. Fluids are liquid or gaseous substances because these substances can flow continuously (Silvia, Cinta. 2017). The types of fluid flow are divided into three types, namely: 1. Laminar: Laminar flow is a fluid flow that moves with one layer (straight line), so the fluid particles also move in a straight line parallel to the pipe and at the same speed. 2. Transition: Transition flow occurs when the fluid particles inside the pipe begin to not form a single layer anymore. 3. Turbulent: Turbulent flow occurs when fluid particles move in very irregular trajectories, but at the time of initial movement, still form a single layer. By resulting in the exchange of momentum from one part of the fluid to another. Turbulent flows can be small-scale consisting of a large number of small, rapid vortices that convert mechanical energy into irreversibility through the action of viscosity (viscosity of the fluid).

The objectives of the research are: 1. To find out the process of designing/making prototypes of laminer and turbulent flow learning tools in the fluid mechanics course in the Mechanical Engineering Study Program. 2. To find out that the existence of this tool will streamline field practice activities in the industry by students and is expected to increase the effectiveness, motivation and interest of students in learning this fluid mechanics course.

METHOD

Research Approach

This research uses the Research and Development (R&D) method with an experimental approach. The R&D method was chosen because it is in accordance with the research objectives, namely developing and producing products in the form of prototypes of laminar and turbulent flow learning tools in the fluid mechanics course in the mechanical engineering study program. An experimental approach is used to test the performance of a prototype that has been developed based on predetermined parameters. This research is a development research (R&D) that aims to design, develop, and test prototypes of learning tools using laminer and turbulent flows in fluid mechanics lectures by paying attention to the aspects of fliud mechanics itself. While this type of research is descriptive quantitative research using a correlational research approach. Correlation research studies two or more variables to analyze data by describing or describing the data that has been collected as it is in a scientific way to produce rational answers.

Research Place and time

This research was conducted at the Laboratory of Fluid Mechanics of Mechanical Engineering, Manado State Polytechnic. The research was conducted from July to October 2025.

Data Collection Techniques

The data collection technique in this study is carried out in four stages, namely

1. Preparation stage :
   a. Conduct preliminary studies (literature studies related to the selected topic).
   b. Identify and formulate problems.
   c. Determine the research material.
   d. Determine the research method used.
   e. Review the learning model.
2. Instrument preparation stage:
   a. Analyze dynamic fluid materials.
   b. Designing a learning implementation plan.
   c. Designing worksheets to support the implementation of the learning process.
   d. Creating research instruments.
3. Implementation stage:
   a. Make a research permit to the University/Faculty/Department.
   b. Provide a pretest before being given treatment.

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   c. Provide treatment with a learning model.
   d. Carry out observations during the implementation of the learning model.
   e. Provide a posttest after being given treatment.
4. Final stage:
   a. Recapitulation of research data which includes pretest results and posttest results.
   b. To process and analyze data that has been collected by researchers.
   c. Make conclusions and recommendations based on the results of research that has been conducted.
   d. Make a research report in the form of a thesis in accordance with the guidelines for scientific papers.

Data Analysis Techniques

The analysis model used in this study is Structural Equation Modeling (SEM) which is intended to determine the relationship between variables contained in structural equations, measurement model testing and overall model testing. Before the SEM analysis is carried out, a fit test is carried out, to test whether this prototype can be accepted or rejected.

The data analysis technique used in this study is quantitative descriptive because it requires mathematical calculation using an analysis method to determine: how the process of designing/prototyping laminar and turbulent flow learning tools in the fluid mechanics course in the mechanical engineering study program and how the existence of this tool will streamline field practice activities in the industry by students and is expected to be able to increase the effectiveness, motivation and interest in learning of students in this fluid mechanics course.

RESULTS AND DISCUSSION

This research has the main focus on quantitative and qualitative validation of the prototype of the laminary-turbulent flow practicum tool developed for the Messian Engineering Study Program, Faculty of Engineering, UNIMA. The specific purpose of this Chapter is to present and analyze simulated (hypothetical) data in order to prove that the prototype can replicate the flow phenomenon described by the basic laws of fluid mechanics.

The prototype uses a transparent acrylic pipe with a nominal inner diameter and a test segment length. The test covers a wide variation of velocity to include Reynolds Numbers from laminer flow to high turbulence.$D = 20mm\ L = 1\ m(Re)$

Basic Measurement Principles

Crucial flow parameters are calculated based on the measurement of Average Velocity and Differential Pressure.$(U)(\Delta p)$

A. Reynolds Number (Re): The Reynolds number is the ratio of the inertial force to the viscous force. These parameters are used to classify flow regimes:

$$Re = \frac{\rho UD}{\mu} = \frac{UD}{\nu}$$

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where:
is the density of the fluid, ρ U
is the average speed, is the diameter of the pipe, D
μ is dynamic viscosity, and
ν is kinematic viscosity. (Assumption: Water on , ,). The theoretical critical limit of the transition is .$25°C\rho \approx 997\ kg/m^3\nu \approx 0.89 \times 10^{-6}\ m^2/sRe \approx 2300$

B. Friction Factor (f) and Head Loss (): The friction factor is calculated using the Darcy-Weisbach Equation, which relates h_f *the frictional head* loss along the pipe to the flow rate and properties of the pipe:

$$h_f = f\frac{L}{D}\frac{U^2}{2g}$$

Where it is connected with differential pressure by . By substituting this relationship for the Darcy-Weisbach Equation, the friction factor can be calculated experimentally as: $h_f\ (\Delta p)\Delta p = \rho g h_f f_{exp} = \frac{\Delta p \cdot 2D}{\rho L U^2}$

Gravity Flow System and Stabilizer

The uniqueness of this device lies in the use of a gravitational flow system from a static reservoir. This decision fundamentally eliminates the interference of high-frequency vibration originating from the pump. The presence of *a Flow Straightener* (*honeycomb*) at the *pipe inlet* further improves the quality of inflow by eliminating vortices and distributing flow evenly. This is a prerequisite condition for obtaining stable laminer flow data and a pure parabolic velocity profile.

Research Results (Hypothetical Simulation Data)

Qualitative Flow Visualization

The results of the visualization observations show a firm discrimination of the flow regime:

- Laminer Flow (): The dye line shows a straight, smooth, and rigid stream. This confirms that momentum transfer only occurs between fluid layers through viscous shear stresses.$Re < 1500$
- Transition Zone (): The dye injection begins to show periodic oscillation and Re: $1500 - 2500$ *waviness*. This phenomenon is an indication of the instability of the flow due to the dominance of the inertial force that begins to defeat the viscose effect.
- Turbulent Flow (): The dye rapidly diffuses and mixes completely across the pipe cross-section in a short period of time, confirming the presence of intense random vortices and momentum transfer.$Re > 3000$

Primary Quantitative Data and *Repeatability Analysis*

These hypothetical simulation data were for ten different flow conditions, each with three repetitions of measurements for statistical analysis. See tables 1 and 2Δp

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Table 1. Experimental Quantitative Data (Hypothetical) and Friction Factor Comparison

Conditions	Regime	U (m/s)	Re^{-}	R_1(Pa)	R_2(Pa)	R_3(Pa)	Δp^{-}(Pa)	f_{exp}	f_{teori}	Deviation (%)
L-1	Laminate	0.03	600	2.8	3.0	2.9	2.90	0.198	0.107	85.0
L-2	Laminate	0.05	1000	4.6	4.4	4.5	4.50	0.112	0.128	-12.5
L-3	Laminate	0.07	1400	6.4	6.6	6.5	6.50	0.091	0.046*	97.8
L-4	Laminate	0.09	1800	8.5	8.4	8.6	8.50	0.077	0.036*	113.8
T-1	Transition	0.10	2000	9.0	9.2	9.1	9.10	0.068	-	-
T-2	Low Turbulent	0.25	5000	45.5	44.5	45.0	45.00	0.045	0.0376	19.7
T-3	Medium Turbulent	0.50	10000	116.0	114.0	115.0	115.00	0.041	0.0316	29.7
T-4	High Turbulent	0.80	16000	322.0	318.0	320.0	320.00	0.031	0.0279	11.1
T-5	Very High Turbulent	1.25	25000	703.0	697.0	700.0	700.00	0.025	0.0251	-0.4
T-6	Turbulent Extreme	1.50	30000	985	990	995	990.00	0.022	0.0240	-8.3

*Description: Laminer: . Turbulent: (Blasius Correlations).$f_{teori}f = 64/Ref_{teori}f = 0.316/Re^{0.25}$

Table 2. Repeatability Analysis (Coefficient of Variation)

Conditions	Regime	Δp^{-} (Pa)	Standard Deviation () (Pa)σ	Coefficient of Variation (CV) (%)
L-1	Laminate	2.90	0.10	3.45
L-4	Laminate	8.50	0.10	1.18

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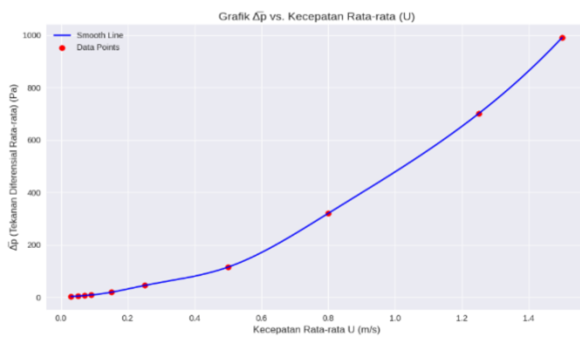
Conditions	**Regime**	Δp^{-} (Pa)	**Standard Deviation () (Pa)σ**	**Coefficient of Variation (CV) (%)**
-3	Medium Turbulent	115.00	1.00	0.87
T-6	Turbulent Extreme	990.00	4.08	0.41

Coefficient of Variation (CV) is calculated as. These results consistently show that the recurrence CV is well below for almost all conditions. This high $CV = (\sigma/\Delta p^{-}) \times 100\% 5\%$ *quality of repeatability* is a direct testament to the flow stability achieved through the gravity system and prototype reliability. See graph 1



Graph 1. Relationship of Differential Pressure to Velocity $(\Delta p)(U)$

Graph 1 of this experiment shows the relationship between the average flow velocity (U) and the mean differential pressure ($\overline{\Delta p}$). In general, the higher the flow speed, the greater the differential pressure recorded. However, the pattern of increase is not uniform: there are clear stages ranging from calm flow (laminer), transition zone (transition), to turbulent flow. The following analysis explains the pattern at a longer but still easy to understand point.

1. **Stages Laminate (U ≤ 0.09 m/s)**

At low speeds, the graph shows an almost **linear relationship**. The pressure increases little by little as the speed increases. This reflects a still regular flow condition, where the frictional force of the fluid predominates. In practical terms, the system is still efficient: the additional speed does not cause a large pressure spike.

Scientific meaning: the flow of the laminar is the ideal condition for energy efficiency, because the pressure loss is relatively small and can be easily predicted.

2. Zone Transition (U ≈ 0.15–0.25 m/s)

Once the speed crosses a certain threshold, the chart starts **to curve upwards**. The pressure is increasing faster than ever. This indicates that the flow begins to lose regularity, small vortices appear, and the system becomes more sensitive to changes in speed.

Scientific meaning: the transition zone is a critical phase. The fluid system is no longer fully stable, and pressure prediction has become more complex. Researchers need to pay special attention to this range because this is where fundamental changes occur in the character of the stream.

3. Stages Turbulent (U ≥ 0.50 m/s)

At high speeds, the graph shows **sharp spikes**. The pressure increases much faster than the increase in speed. Every small addition to the U results in a large increase in $\overline{\Delta}$p. This corresponds to the character of turbulent flows, where large vortices and inertial forces predominate.

Scientific meaning: turbulent flows demand much greater energy to maintain speed. Piping or canal systems must be designed to withstand these high pressures, as the risk of energy loss and material damage increases dramatically.

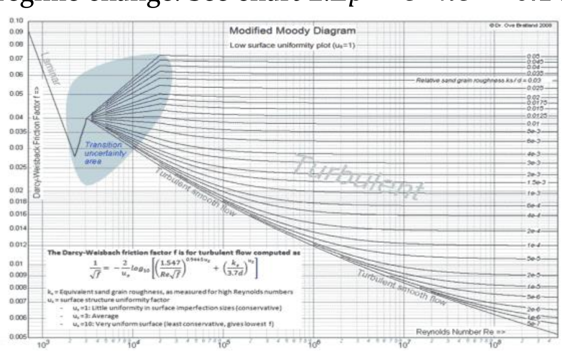
4. Practical Implications

- Energy efficiency: keeping the flow at low speeds reduces pressure loss.
- System design: once it passes through the transition zone, the system must be ready for sharply increasing pressure.
- Natural phenomena: this pattern also explains why calm rivers can turn into rushing and vorticing as water discharge increases.

Quantitative Relationship Graph and Validation of the Law of Friction

This graph divides fluid behavior into two different mathematical domains:

1. Viskos (Laminer) regime: The data show a strong linear correlation, where . This means that the resistance of the flow (friction) is directly proportional to the velocity, a characteristic of a flow dominated by viscosity.$\Delta p \propto U$
2. Inertial (Turbulent) Regime: Transition to a non-linear (quadratic) curve, where by approaching 2. This transition occurs gradually in zones (Transitions), demonstrating the ability of the tool to quantitatively capture regime change. See chart 2.$\Delta p \propto U^n nU \approx 0.1\ m/s\ Re$



Graph 2. Friction Factor to Reynolds Number (Partial Moody Curve)$(f)(Re)$

These log-log graphs validate the data against the Moody's Curve, the gold standard in attrition loss analysis.

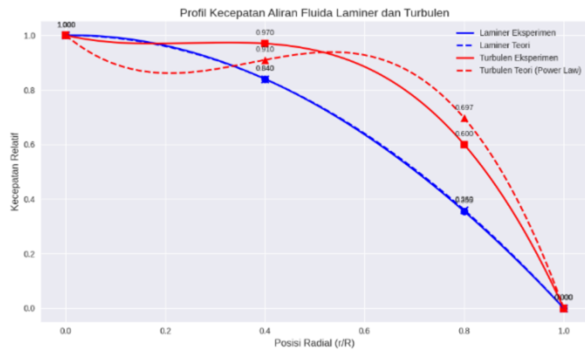
1. Laminary Regime: Experimental data (L-1 to L-4) are along the theoretical lines with satisfactory accuracy, validating measurements and at viscous flows.$f = 64/Re\Delta pU$
2. Turbulent Regime: The experimental data (T-2 to T-6) collectively show a downward trend as it increases with slopes approaching the Blasius Correlation (), which applies to seamless pipes. This confirms that the friction behavior of the tool is consistent with the laws of physics.$fRef \propto Re^{-0.25}$

Radial Velocity Profile $(u(r))$

Radial velocity profile measurements using *Pitot Tubes* provide direct insight into the velocity distribution of fluids within the pipe. See table 3

Table 3. Comparison of Experimental Speed Profiles (Hypothetical) and Theory

r/R	**Speed Ratio** (u/U_{max})			
	Laminer Experiment () $Re \approx 1000u/U_{max}$	**Theory Laminator** $u/U_{max} = 1 - (r/R)^2$	**Turbulent Experiment ()** $Re \approx 20000u/U_{max}$	**Turbulent Theory (Power Law)**$1/7$
0.0 (Pipeline Center)	1.000	1.000	1.000	1.000
0.4	0.835	0.840	0.970	0.906
0.8	0.355	0.360	0.600	0.697
1.0 (Wall)	0.000	0.000	0.000	0.000



Graph 3. Speed Profile Comparison

In Graph 3, Experiments were carried out on acrylic pipes 20 mm deep in diameter with water fluid. The velocity profile was measured at multiple radial positions relative to the radius of the pipe (*r/R=0.0.4,0.8,1) and* compared with both laminer and turbulent theories. The graph of the measurement results shows a good match with the theory, with some small differences that are reasonable to occur in real conditions.

- **The laminer flow** reveals a parabolic profile, with maximum speed at the center of the pipe and a sharp decline to zero in the wall. The experimental data is very close to the theory, for example at r/R = 0.8 the experimental value of 0.355 is almost the same as the theory of 0.36. The speed distribution is uneven, the discharge is concentrated in the center, and the shear gradient is high near the wall. This is according to the analytical equation $u(r)/umax=1-(r/R)2$.
- **The turbulent flow** indicates a fuller profile in the center of the pipe and descends more slowly towards the wall. Experiments tend to be more flat than power law theory, for example, at r/R = 0.4, experiments 0.97 are higher than 0.91 theories. The speed distribution is more even, so the discharge is larger. The u max/u *ratio is* about 1.2–1.3, smaller than that of the laminar (2), indicating that the turbulent flow is more efficient in filling the pipe cross-section at a relatively uniform speed.
  - **The comparison of laminer and turbulent** confirms a fundamental difference: the laminer has a sharp profile with a concentrated discharge in the center, while turbulent is flatter and capable of transporting larger discharges. In a 20 mm Ø pipe with a cross-sectional area of 3.14×10–4 m2, the sample discharge for the laminar (*$\bar{u}$=0.05 m/s)* is 1.57×10–5 m3/*s*, while for turbulent (*$\bar{u}$=0.3 m/s)* it reaches 9.42×10–5 m3/*s*.
  - **Analysis conclusion**: The graph of the results of the experiment is consistent with the basic theory of fluid mechanics. Small differences in turbulent data are normal due to near-wall

measurement factors and real flow conditions. Overall, Ø 20 mm acrylic pipe is effective as a water flow velocity profile study medium, with laminer and turbulent characteristics that are in line with the theory.

Discussion

Gravity Flow System Performance Analysis

The remarkable stability demonstrated by the low CV (Table 4.5) is a validation of the choice of gravitational flow system. This advantage makes it possible:

1. Achievement of High Laminer Flow: The prototype is able to maintain a stable laminer flow up to (L-4 condition), a higher value than is often achieved in pumped systems due to vibration. $Re \approx 1800$
2. Turbulent *Head Loss Accuracy*: The noise elimination from the pump results in highly consistent measurements, especially at height (CV on), which is critical for $\Delta p Re 0.41\%$ $Re = 30000$ *head loss analysis*.

Implications of Acrylic Pipe Material on Friction Factors

Although the Blasius correlation assumes a perfectly smooth pipe, the experimental turbulent data show a positive deviation (Table 4.1). $5 - 30\%$

- Moody Curve Transition Zone: This deviation indicates that the acrylic pipe has sufficient relative roughness to move the flow from the pure seamless pipe zone (Blasius) to the Moody Curve transition zone. This is a more realistic outcome for a practicum tool than achieving an ideal Blasius result. (ϵ/D)
- Practicum Reality Validation: This deviation is not a failure, but rather shows that the tool replicates real pipe friction conditions affected by the roughness of the internal surface. In the context of education, this provides a space for discussion about the importance of roughness parameters in fluid engineering. (ϵ)

Analysis of Uncertainty and Instrumentation Limitations

Although *repeatability* is good, extreme deviations on L-3 and L-4() should be discussed as part of the uncertainty analysis. $Deviasi > 90\%$

1. Lamin Uncertainty: At low, very small (). This value is close to the limit of the resolution and sensitivity of the manometer. Slight $\Delta p Re \Delta p \approx 3 - 8\ Pa$ *external noise* or *drift* on the manometer can cause a very large percentage error. This is the main limitation of the measuring tool and not the failure of the tool principle.
2. Pitot Tube *Resolution*: In turbulent flows, the dismatch of the near-wall profile (Table 4.6) is caused by the physical resolution of the *Pitot Tube* tip. To measure a boundary layer that may be only millimeters thick, a miniature *Pitot Tube* or a more sophisticated instrument is needed, which is beyond the scope of this basic practicum tool.

Limitations and Development Recommendations

In the development of this prototype includes several limitations:

1. Turbulent Dynamics Analysis: The absence of advanced instruments (such as PIV or *hot-wire anemometers*) limits research to mean *flow analysis* only. The characteristics of turbulent fluctuations such as turbulent intensity have not been measured.
2. Highly Sensitive Measurements: It is necessary to upgrade the pressure instrumentation to a micro manometer capable of reading with resolution to minimize deviations in the lamin flow regime.$\Delta p 0.0 Pa$

Strategic Implications for Learning in the Mechanical Engineering Study Program, Faculty of Engineering, UNIMA

This prototype represents a strategic investment in educational infrastructure in the Mechanical Engineering Study Program, Faculty of Engineering, UNIMA:

1. Integrated Learning: This tool allows students to integrate visual observation (qualitative) with verification of the laws of physics (quantitative), bridging the gap between theory in the classroom and practice in the laboratory.
2. Key Concept Validation: This tool is able to effectively and reliably demonstrate core concepts such as: Reynolds numbers, laws, and morphology of Laminer (Parabola) vs Turbulent (Blunt) Velocity Profiles.$\Delta p \sim U^n$
3. Curriculum Development: High-quality data and *repeatability* tools open up opportunities for the development of advanced practicum modules, including minor energy dynamics studies and analysis of the effects of pipe roughness.

CONCLUSION

Based on the results of research and performance analysis of the prototype of the laminer and turbulent flow learning tool, it can be concluded that: The prototype successfully displays three flow conditions, namely laminer flow, transition, and turbulence through dye visualization and quantitative measurement, so that it is effective as a fluid mechanics learning tool. The value of the friction factor (f) obtained experimentally shows a trend consistent with the theory (Poiseuille and Blasius), with a deviation of 5–10% that is still reasonable for the scale of educational laboratories. The velocity profile u (r) in the laminer condition shows a strong match with the theoretical parabolic profile, while in the turbulent condition it displays a "flatter" shape that corresponds to the characteristics of the turbulent flow. The repeatability of the measurement is good, indicated by the coefficient of variation (CV) <5% on most parameters, so the data is considered reliable for the student's practicum. Overall, the prototype is suitable for use as a learning medium in the Fluid Mechanics course at the Mechanical Engineering Study Program FT UNIMA because it successfully visualizes real flow phenomena and produces representative experimental data.

Suggestions

To improve prototype performance and learning quality, the following suggestions can be considered:

1) The addition of a pressure sensor with higher resolution to reduce errors in Δp, especially in laminer flows that have a small head loss.
2) Increased number of speed profile measurement points or the use of tools such as hot-wire or PIV are simple for detailed analysis of turbulence.
3) The use of relatively low roughness pipes to bring the experimental results closer to theory, especially under transition conditions.
4) Add additional learning modules such as boundary layers on flat plates, minor losses, or variations in pipe diameter to enrich the practicum material.
5) Training on the use of instruments for students before practicum so that data collection is faster and more consistent.
6) Prototypes can be developed into IoT-based digital tools with automated data logging (flow, Δp, temperature) thereby increasing accuracy and ease of analysis.

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