Unizik Journal of Technology, Production and Mechanical Systems (UJTPMS)

journal homepage: https://journals.unizik.edu.ng/index.php/ujtpms/about
PRINT ISSN: 1115-7143 || ONLINE ISSN: 1115-7453

Design and fabrication of a domestic vacuum cleaner: an engineering approach to airflow and particle entrapment

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ARTICLE INFO

Article history:
Received Oct 2, 2024
Revised Oct 28, 2024
Accepted Oct 29, 2024

Available online Nov 15, 2024

Keywords:
Vacuum cleaner design, airflow analysis, particle entrapment, filtration efficiency, fabrication process

ABSTRACT

This project focuses on the design and fabrication of a domestic vacuum cleaner. The design process involved selecting key components, including the motor, fan, filter, and housing materials, and calculating essential parameters such as flow velocity, Reynolds number, and volume flow rate. The analysis considered factors like pressure drops, hose length, and filtration efficiency. Seasonal variations, rug texture, and dust density (1.172 kg/m³ at 27°C) were factored into the design, with careful consideration of the maximum particle size to be captured. The project comprised three stages: working drawing, performance analysis/design, and actual fabrication. Assumptions were made for ideal airflow conditions. The final vacuum cleaner, constructed with a PVC hose, plywood housing, and a 1100 RPM motor, demonstrated effective dust collection. Recommendations were made to improve noise reduction, durability, and performance through material and design enhancements

1. Introduction

The design and fabrication of domestic vacuum cleaners have evolved significantly since their inception in the early 20th century, incorporating advancements in engineering, particularly in the domains of airflow dynamics and particle entrapment. Domestic vacuum cleaners are household devices designed to remove dust, dirt, and debris from floors, carpets, and other surfaces [1]. They operate by creating a partial vacuum using a motor-driven fan, which generates suction to draw in particles through an intake port. Modern designs vary widely, including handheld, upright, canister, and robotic models, each suited to different cleaning tasks. Vacuum cleaners typically use filters, such as High-Efficiency Particulate Air (HEPA), to trap fine particles and allergens, improving air quality in the home [2]. Lightweight and efficient, these appliances are essential tools for maintaining cleanliness and hygiene in residential environments [3; 4].

The concept of the vacuum cleaner dates back to 1901 when Hubert Cecil Booth introduced a machine that utilized suction to remove dust. Booth's design, which used a large, horse-drawn, petrol-driven unit with hoses fed through windows, was a significant departure from previous methods that relied on compressed air to blow dust away rather than collect it [5]. This innovation laid the foundation for subsequent designs that focused on improving suction efficiency and dust collection. In 1907, James Murray Spangler, a janitor suffering from respiratory issues due to dust exposure, developed the first portable electric vacuum cleaner. Spangler's design, which used a fan motor, a soapbox, a broom handle, and a pillowcase, introduced the use of a cloth filter bag and cleaning attachments, which became standard in later models. This design was further commercialized by William H. Hoover, who implemented a marketing strategy that included a free home trial, leading to widespread adoption of the vacuum cleaner [6].

Designing a domestic vacuum cleaner involves optimizing suction power, filtration, and ergonomic features for user comfort. Advanced materials like carbonized wood and silicon dioxide composites can enhance durability and performance [7]. The fabrication process includes prototyping, injection molding for plastic parts, and rigorous testing to ensure functionality and safety. Integrating these materials supports sustainability by reducing reliance on conventional resources and enhancing the product's longevity [8]. This approach not only improves vacuum cleaner efficiency but also aligns with eco-friendly practices, reflecting a growing emphasis on both performance and environmental responsibility. A vacuum cleaner operates by drawing air

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through a nozzle using a motor-driven fan. The airflow creates suction, pulling dirt and debris into a dustbin or bag [9]. Filtration systems capture fine particles and allergens, ensuring clean air is expelled back into the room.

The operation of a vacuum cleaner is fundamentally based on principles of fluid mechanics and roto-dynamics. The key to its function is the creation of a partial vacuum within the device, which is achieved by a rotating fan [10]. The rotation of the fan causes a pressure drop within the machine, leading to a difference in atmospheric pressure inside and outside the vacuum cleaner. This pressure difference forces air to flow into the vacuum, entraining dust and debris along with it [11]. The principle of entrainment is central to the effectiveness of vacuum cleaners. As the air is drawn into the vacuum, it exerts a drag force on dust particles, which are then carried into the machine and trapped by a filter. The effectiveness of this process is influenced by several factors, including the velocity of the air, the size of the dust particles, and the design of the filter system [12]. For instance, the inclusion of bristles on the vacuum's inlet port helps to agitate and loosen debris, making it easier for the air to carry it into the machine.

Over the years, vacuum cleaner designs have diversified to meet different cleaning needs, resulting in a variety of models such as wet/dry utility vacuums, handheld vacuums, and electric brooms [13]. Each design adheres to the same basic principles but is tailored to specific tasks. For example, wet/dry vacuums are designed to handle both liquid and solid waste, utilizing a more robust filtration system to separate different types of debris [14]. The materials used in the construction of vacuum cleaners have also evolved, with modern designs favoring lightweight and durable materials such as plastics and high-strength alloys [15]. These materials not only reduce the overall weight of the machine but also improve its durability and ease of use. Additionally, advances in motor technology have led to more powerful and efficient vacuum cleaners that consume less energy while delivering superior cleaning performance [16]. The need for the study therefore originated from the increasing demand for more efficient and environmentally friendly household appliances. Traditional vacuum cleaners often struggle with energy efficiency and effectiveness in capturing fine particles, particularly in households with high levels of allergens [17]. While there have been advancements, many designs still fail to optimize airflow and particle entrapment, leading to lower performance and higher energy consumption.

Moreover, as indoor air quality becomes a growing public health concern, there is a pressing need for vacuum cleaners that can effectively trap microscopic particles like dust mites, pollen, and other allergens [18]. The current market offerings often lack innovation in this aspect, leaving a gap that this study aims to address by exploring engineering solutions that enhance the functionality and efficiency of domestic vacuum cleaners. This research is vital to developing more effective cleaning devices that not only improve household cleanliness but also contribute to better health outcomes, particularly for individuals with respiratory conditions.

2.0 Materials and Method

The vacuum cleaner is a machine designed to remove dust and small particles from floors using an air pump, which is essentially a fan with an impeller. The design consists primarily of three main components: an electric motor powered by alternating current, a rotating assembly of ramps (essentially a compressor), and a filter housed in an airbag. Secondary components include the hose and the housing compartment. The power of the electric motor was calculated as the sum of the power required to overcome pressure drops across the various components of the machine.

2.1 Power Calculation

The power required to rotate the impeller was determined using the following equation:

$$W_{impeller} = MC_pT_o\left[\frac{P_r^{\gamma^{-1}}}{\gamma}\right]$$

where:

- C_p is the specific heat capacity of air at constant pressure,
- M is the mass flow rate,
- T_o is the upstream temperature,
- P_r is the pressure ratio across the impeller, and
- γ is the isentropic compression constant for air.

The power required by the filter was calculated using:

$$W_{filter} = \Delta P_{filter} \times Q$$

where:

- ΔP_{filter} is the pressure drop across the filter, and
- Q is the volume flow rate.

The power required to generate suction was given by:

$$W_{suction} = Q \times \Delta P_h$$

where:

- ΔP_h is the pressure drop at the inlet hose.

The total power rating of the electric motor was determined by summing the power required to turn the impeller, the power needed for the filter, and the power required at the inlet hose:

$$W_{motor} = W_{impeller} + W_{filter} + W_{hose}$$

The rotational speed of the motor, expressed in revolutions per minute (RPM), was calculated using the formula:

$$RPM = \frac{Frequency \times 120}{Number\ of\ poles}$$

For this design, the motor speed was 110 RPM, and a motor power rating of 1.7 kW was selected based on the calculated power requirements at various pressure drops. The electric motor used was a single-phase motor powered by alternating current.

2.2 The Fan

A fan is any device that produces a current of air. The fan used in this design featured a rotating impeller to generate flow and a stationary casing to guide the air in and out of the impeller. The specific speed of the fan, which determines its type, was calculated using the following equation:

$$N_s = \frac{NQ^{1/2}}{(gH)^{1/4}}$$

where:

- N is the fan speed in revolutions per second,
- Q is the volume flow rate, and
- H is the head developed across the fan.

The impeller, the primary working component of the fan, produces airflow. The specific speed was used to determine the appropriate fan type, ensuring that the centrifugal head was equal to or greater than the head developed across the fan, as expressed by:

$$\frac{U_2^2 - U_1^2}{2} \geq H$$

where:

- U_2 is the blade velocity at the outlet,
- U_1 is the blade velocity at the inlet, and
- H is the head developed across the fan.

2.3 The Filter

The filter's purpose was to separate dust particles from the entrained air while allowing clean air to pass through. Positioned before the fan to protect the motor from dust damage, the filter was made of cotton, configured in a bag form with loose cotton wool inside to capture larger particles and a finer cotton matrix for smaller dust particles. The filtering process, or air cleaning, was achieved by reducing the pore size as the filter aged, which improved its efficiency.

The filter's cleaning efficiency was defined as:

$$Cleaning\ Efficiency = \frac{Mass\ of\ dust\ trapped}{Mass\ of\ air\ entrained}$$

The pressure drop across the filter was a measure of the force required to move air through the filter at a given velocity, contributing to the overall pressure drop in the system.

2.4 Filter Selection

Filter selection was based on several specifications, including available area, volumetric flow rate, maximum allowable pressure drops, filter efficiency, and the type of contaminants to be filtered. A cotton filter was chosen for its low power requirements and effective dirt trapping capabilities, with a pore size of 0.25 mm and a thread diameter of 0.24 mm.

2.5 Suction Hose

The suction hose consisted of both flexible and rigid components. The flexible part was made of non-collapsible rubber, while the rigid end was made of strong polyvinyl chloride (PVC) plastic. The hose length was calculated to be 1.87 meters, with a diameter of 0.03 meters. The pressure drop in the hose was calculated to be 1.577 kN/m².

2.6 Pressure Drop, Total Energy, and Speed Across the Vacuum Cleaner

Using Bernoulli's equation, it was determined that the pressure inside the vacuum cleaner fell below atmospheric pressure when the fan rotated. This created suction, causing air to accelerate towards the inlet hose. The total pressure in the hose was 99.363 kN/m², with a constant speed due to the consistent hose diameter. As air flowed past the filter, pressure dropped further, and the fan's rotation increased air velocity, converting kinetic energy to static pressure, which equalized with atmospheric pressure as air exited the exhaust port.

2.7 Housing Compartment and Specifications

The vacuum cleaner was designed to be compact, with dimensions of 600 mm by 300 mm by 260 mm. It featured a rigid steel framework for support and thick plywood sides for structural integrity.

2.8 Design Process

During the design process, several critical choices and considerations were made to ensure the vacuum cleaner effectively removed dust from rugs. Factors such as rug texture, fan type, motor power, inlet hose length, and filter material were carefully evaluated. Standard fluid mechanics equations and formulas were employed to determine these parameters accurately. To determine the appropriate fan type and motor power, the Reynolds number of flow and the volume flow rate were first calculated. This involved computing the airflow velocity required to entrain a particle with a 0.01 m diameter along the duct and across the selected filter. The forces acting on the particle, including frictional drag, particle weight, and buoyant force, were analyzed. The frictional drag force was calculated using the equation:

$$F_D = \frac{1}{2}\rho A V_r^2 C_D$$

where:

- ρ_A is the density of air,
- V_r is the velocity of airflow, and
- C_D is the coefficient of drag.

The weight of the particle was determined using:

$$W_p = mg = \frac{\pi d^3 \rho_p g}{6}$$

where:

- m is the mass of the particle,
- g is the acceleration due to gravity,
- d is the diameter of the particle, and
- ρ_p is the density of the particle.

The buoyant force acting on the particle was calculated as:

$$\mathrm{B} = \frac{\pi d^3 \rho A g}{6}$$

For the particle to be effectively sucked into the vacuum cleaner, the sum of the drag force and buoyant force had to be equal to or greater than the particle's weight:

$$F_D + B \geq W_p$$

By substituting and simplifying these expressions, the velocity of airflow V_r was obtained.

2.9 Volume Flow Rate and Reynolds Number

The volume flow rate Q was then calculated by multiplying the hose cross-sectional area A_D by the velocity of airflow V_r:

$$Q = V_r \times A_D$$

Given that the diameter of the inlet hose was 30 mm, these calculations provided the necessary parameters for the design of the vacuum cleaner.

3.0 Results

3.1 Determination of flow velocity, Reynolds number and volume flow rate

V_r = Velocity of air stream
F_D = Drag Force
A_P = Area of spherical particle
d = Maximum diameter of Particle
D= Diameter of Conduit
R_e = Reynolds Number
μ_A = Dynamic Velocity of air
C_D = Coefficient of Drag
C_e = Coefficient of entry (Bell Mou9h)
PA = Density of air
Q_A = volume flow rate of air

M_p = Mass of particle

3.1.1 Assumptions and constants

Operating Temperature = 27^0C
Density of air at 27^0C = $1.172kg/m^3$
Dynamic Viscosity of air at 27^0C = 18.465 x 10-6kg/ms
Inlet hose is smooth (roughness factor is 0.00000061 PVC pipe).
Maximum Diameter of particle considered = 10mm = 0.01m
At 1000<Re<100,000; CD = 0.44
Diameter of pipe or hose = D = 0.03m

3.1.2 Analysis

$F_D = ½ (\rho_A V_r^2 A_P) C_D$
$AP = \pi d^{3/4}$ (particle spherical)
Equating the drag force F_D to the maximum weight of particle, we obtain the flow velocity.
$F_D = ½ (\rho_A V_r^2 A_P) C_D$ mg-FB
Assume a ball of diameter 0.01m and density of $11400kg/m^3$ to be sucked by the vacuum cleaner.
$m = \pi d^{3/6} p_{lead}$ = volume x density
$mg = \pi d^{3/6} p_{lead}\ x\ g$
$F_B = \pi d^3 p_A\ x\ g$
$R_e = (P_A V_r D)/\mu_A$
Q = Q x VrA
$A_D = \pi D^2/4$

3.1.3 Synthesis

PA = given
$mg = \pi d^{3/6} p_{lead}\ x\ g$
$AP = \pi d^{3/4}$
$V_r = (mg-F_B)(1/2 P_A A_P C_D)^{1/2}$
$A_D = \pi D^2/4$
$V_A = C_e \times V_r$ (actual velocity in the hose)
$Q = A_D \times V_A$
$R_e = (\rho_A \times V_A \times D)/\mu_A$

Table 1: Flow Parameters

S/N	Symbol	Formular	Units	Computation	Values
1	P_A	Given	Kg/m^3	1.172	1.172
2	M_P	$\pi d^{3/6\ Plead-} P_A{}^g$	N	$(3.142/6)(0.01)^3(1.1400)\ 1.172)9.81$	0.058
3	A_P	$\pi D^2/4$	M^2	$3.142 \times (0.01)^{2/4}$	7.8x 10^5
4	V_r	$(mg-F_B)(1/2P_A A_P C_D)^{1/2}$	m/s	$(0.058)/0.5x1.172x7.86x10 \times 0.44^{1/2}$	53.49
5	A_P	$\pi d^{3/4}$	M^2	$3.142 \times (0.03)^{2/4}$	7.07x 10^4
6	Q	Q x VrA	M^3/S	$7.07 \times 10^{-4} \times 53.49 \times 0.97$	
7	Re	$(P_A V_r D)/\mu_A$		$(1.172 \times 51.88\ x0.03)/18.465 \times 10^{-6}$	

3.2. Calculations of pressure drops and suction hose length

P_o = Ambient Pressure
P_{hI} = pressure at hose inlet
P_{h2} = Pressure at hose outlet
T_o= Ambient Temperature
R = Air Constant
D_I = "Eye Diameter
D_2 = Impeller Diameter
N = Speed of Fan(rpm)
$_{A2}$ = Area of the impeller
A_{filter} = Area of the filter
V_{filter} = face velocity of filter
V_{out} = Velocity of flow at outlet of impeller
ΔP_h = Pressure drop in the hose
ΔP_r = Pressure drop across filter
L = length of hose pipe

T_I = Temperature rise across fan
C_p = specific heat capacity of air at constant pressure
R_t = Specific resistance of filter
K = roughness factor for Pvc pipe=0.00000061m

3.2.1 Assumptions Constant and Conditions
Density is constant and hence flow is incompressible. Pipe inner surface area is smooth, therefore using BLASIUS formular for the coefficient of friction.
$f = 0.079/R_e^{1/4}$
$T_o = 27^0C = (27+273.16) = 300k$
R_{Art} = 0.2871KJ KgK
b = 0.04(width of impeller)
$C_p = 1.005$
N = 1100rpm
3.2.2 Analysis
$P_o = \rho_A RT_o$
$P_I = P_o - {}^{1/2}P_A v_r^2$
$P_{h2}-P_{hI} = {}^{1/2}P_A \times V_r^2 = \Delta Ph = 4f LPV_r^2/2D$ (for full circular Pipe flow)
$A_2 = \pi d_2 \varphi$
$V_{out} = Q/A_2$
$f = 0.079/Re1/4$
$\Delta_{Pfilter} = u A \times V_{filter} \times R_t$
$P_{TI} = P_{h2} - \Delta Pr$ = Pressure at fan inlet
$P_{h2} = P_{hI} + {}^{1/2}P_A v_r^2 = P_{hl} + \Delta P_h$
$P_{T2}/P_{T1} = P_r$ = Pressure ratio across fan
$y = 1.4$ (isoentropic constant for air)
$W_{fan} = PA \times Q \times \Delta T \times C_p$
$\Delta T = T_1 - T_o$
$T_I = T_o \times (Pr)^{(\gamma - 1)/\gamma}$
A_{filter} = length x width (Lx W)
Resistance of filter is given by the formula

$$B = \frac{dc^2 \times e^3}{16(1-e)^2 \times K_k}$$

where dc = diameter of fiber.
K_k = Kozeny-carman constant.
e = porosity of the material

3.2.3 Kozeny-Carman Constant for different porosity

e..:	0.3	0.4	0.5	0.6	0.7	0.8(%)
K_k-:	3.8	4.9	5.8	6.3	6.6	7.2

fiber used is diameter 0.00024m and has a porosity of 60%

3.2.4 Synthesis
1. $\Delta P_h = {}^{1/2}P_A V_r^2$
2. $P_o = \rho_A RT_o$
3. $P_I = P_o - {}^{1/2}P_A v_r^2$
4. $f = 0.079/Re^{1/4}$
5. $L = 2\Delta P_h = D/4f LP_A V_r^2$
6. $V_{out} = Q/A_2$
7. $P_{h2} = P_{hl} + \Delta P_h \times K$
8. $V_{filter} = Q/A_{filter}$
9. $\Delta_{Pfilter} = R_t \, u A \times V_{filter}$
10. $P_{TI} = P_{h2} - \Delta_{Pfilter}$

Table 2: Pressure Drops and Hose Length

S/N	Symbol	Formula	Unit	Computation	Value
1	ΔP_h	$^{1/2}P_A V_r^2$	KN/m^2	$0.5 \times 1.172 \times (51.88)^2$	1.577
2	P_o	$\rho_A RT_o$	KN/m^2	1.172 x 0.287 x 300	100.94
3	P_I	$P_o - ^{1/2}P_A V_r^2$	KN/m^2	100.94 1.577	99.363
4	f	$0.079/Re^{1/4}$		$0.079/(98786.94)^{1/4}$	0.004
5	L	$2\Delta P_h = D/4fLP_A V_r^2$	M	(2x1577x0.03)/4x0.004x1.172(51.88)1/2	1.87
6	A_{filter}	L xW	M^2	0.2 x0.2	0.04
7	V_{filter}	Q/A_{filter}	m/s	0.0366/0.04	0.9
8	B	$\underline{dc^2 \times e^3}$ $16(1-e)^2 \times K_k$	M	$(0.000245)^2 \times (0.6)^3/16(1-0.6)^2 \times 6.3$	7.7142×10^{10}
9	R_t	I/B	m^{-1}	$1/7.71428 \times 10^{10}$	1296296292
10	$\Delta_{Pfilter}$	$R_t\, u A \times V_{filter}$	KN/m^2	$1296296292 \times (18.465 \times 10^{-6} \times 6.3$	21.542
11	P_{h2}	$P_{hl} + \Delta P_h \times K$	KN/m^2	99.363-1.577x0.00000061	99.362
12	P_{TI}	$P_{h2} - \Delta_{Pfilter}$	KN/m^2	99.363-21.542	77.821
13	P_r	P_{T2}/P_{T1}		100.94/77.821	1.297
14	T_I	$T_o \times (Pr)^{(\gamma-I)/\gamma}$	K	$300 \times (1.297)^{14}$	323
15	ΔT	$T_1 - T_o$	K	323-300	23
16	“”				
17	W_{fan}	$PA \times Q \times \Delta T \times C_p$	Kw	1.023 x 0.0366 x23 x1.005	0.865

3.3. Calculation of head, specific speed, fluid power output and efficiencies

U_1 = Blade speed at inlet
U_2 = Blade speed at output
r_1 = “eye” radius
r_2 = Impeller radius
N= Fan speed
H = Head or energy per unit weight of flow across fan
Ns = Specific speed
ω = Angular speed.

3.3.1 Analysis

$r_2 = d_2/2$
$u_2 = [[(Pr)^{(y-1)/y} -]]\, C_pT1]^1/^2$
also, $u_2 = \pi d_2N/60]$
$H = U^2{}_2/g \quad (u_2Vout/g)\cot\beta_2$
$\beta_2 \;= 50^0$
Ns = NQ ½ (gH)3/4
P_{output} = Fluid power output = ρgHQ
ηm = Mechanical efficiency = $\rho gHQ/Wfan$
Dl = 2/3d2

3.3.2 Synthesis

1. $u_2 = [[(Pr)^{(y-1)/y} -]]\, C_pT1]^1/^2$
2. $d_2 = (60u_2)/\pi N$
3. $A_2 = \pi d_2 b$
4. $V_{out} = Q/A_2$
5. $H = U^2{}_2/g \quad (u_2V_{out}/g)\cot\beta_2$
6. Ns = NQ ½ $(gH)^{3/4}$ (N is in rev/sec)
7. $P_{output} = \rho gHQ$
8. $\eta m = \rho gHQ/W_{fan}$

Table 3: Head, specific speed, fluid power output and efficiencies

S/N	Symbol	Formula	Unit	Computation	Value
1	u_2	$[[(Pr)^{(y-1)/y} -]]\ C_pT1]^{1}/^{2}$	m/s	$(01.077-1)x1.005x323^{1/2}$	5.01
2	d_2	$(60u_2)/\pi N$	M	(60 x4.9)/3.142 x1100	0.0901
3	A_2	$\pi d_2 b$	M^2	3.142 x0.09 x0.04	0.011
4	V_{out}	Q/A_2	m/s	0.0366/0.011	3.327
5	H	$U^2{}_2/g \quad (u_2V_{out}/g)\cot\beta_2$	M	$(4.9)^2$-4.9 x3.327Cot55	12.52
6	Ns	$NQ\ ½\ (gH)^{3/4}$		$18.3x(0.0366)^{1/2}\ (12.52)^{3/4}$	0.527
7	P_{output}	$\rho_A gHQ$	Kw	1.172 x12.52) x 0.0366	0.537
8	nm	$\rho_A gHQ/W_{fan}$	%	(1.172 x12.52 x0.366)/0.865 x100)	68.9

Total power required by the machine is equal to: Power required to turn the blade +power required for flow across filter +suction power. = 0.865+0.779+0.0569=1.7Kilowatt.

4.0 Discussion

The design and fabrication of a domestic vacuum cleaner require a detailed understanding of airflow dynamics and particle entrapment mechanisms. Key parameters such as flow velocity, Reynolds number, volume flow rate, pressure drops, suction hose length, and efficiencies play crucial roles in ensuring the vacuum cleaner's effectiveness and efficiency. The determination of flow velocity, Reynolds number, and volume flow rate is essential for optimizing the performance of a vacuum cleaner. Recent studies have shown that flow velocity, which can be derived from factors such as the drag force, air density, and particle area, is critical for ensuring efficient particle entrapment. For instance, Mattingly [15] highlighted that the volume flow rate is directly proportional to the product of the pipe's area and the actual velocity within the hose, reinforcing the importance of these parameters in achieving optimal performance. This finding is consistent with Brown et al, [19] and Almasi et al, [20], who emphasized that optimizing flow velocity and volume flow rate significantly enhances the vacuum cleaner's effectiveness.

In contrast, research by Buratti et al, [21] focused on the importance of pressure drops and suction hose length in determining a vacuum cleaner's suction power. They found that the pressure drops within the hose, calculated based on factors like the coefficient of friction, hose length, and diameter, plays a significant role in the overall performance. This study also revealed that pressure drops across the filter greatly impact suction efficiency, suggesting that filter resistance should be carefully optimized. This finding contrasts with earlier research by Almasi et al, [20], which posited that the roughness factor of the pipe had a more pronounced effect on pressure drops than filter resistance.

Furthermore, the calculation of head, specific speed, fluid power output, and efficiencies provides insight into the energy dynamics of a vacuum cleaner. Recent studies have emphasized that head, or energy per unit weight of flow, is crucial for evaluating the fan's performance in a vacuum cleaner. Tonmoy et al, [15] demonstrated that specific speed is a critical parameter for enhancing fluid power output and mechanical efficiency. They found that optimizing specific speed, which relates to fan speed and flow rate, leads to significant improvements in vacuum cleaner performance. This finding aligns with the work of Hertzum [3], who also stressed the importance of specific speed in achieving high efficiency and effective fluid power output. While some studies highlight the critical role of flow dynamics, others focus on pressure management and energy efficiency, collectively providing a comprehensive understanding of the factors influencing vacuum cleaner performance. This integrated approach is essential for developing high-performance vacuum cleaners that meet the demands of modern households.

5.0 Conclusion

The study on the design and fabrication of a domestic vacuum cleaner has provided significant understanding into the engineering principles underlying efficient airflow and effective particle entrapment. The key findings and conclusions of this study are summarized as follows:

1. Through detailed analysis and calculations, it was determined that the optimal airflow velocity for the vacuum cleaner is approximately 51.88 m/s. This velocity ensures sufficient drag force to lift particles while maintaining energy efficiency. The design parameters, including the diameter of the hose and the power of the fan, were tailored to achieve this optimal airflow.
2. The study successfully demonstrated that the drag force exerted on particles is adequate to overcome gravitational forces and lift particles from the surface to the collection chamber. The design incorporated a spherical particle drag coefficient of 0.44, which is effective within the range of Reynolds numbers typically encountered in domestic vacuum cleaners. This ensures that particles of varying sizes are effectively captured.
3. The pressure drops calculations revealed that the hose length and diameter play crucial roles in maintaining efficient suction power. A smooth inner surface and appropriate hose length (approximately 1.87 meters) were determined to be essential for minimizing pressure losses and maintaining effective suction. The study highlighted the importance of using materials with low friction coefficients to reduce resistance and enhance performance.
4. The analysis of filter resistance and pressure drop across the filter emphasized the need for an efficient filtration system. The chosen filter demonstrated a resistance of approximately 21.542 kN/m², balancing airflow with effective particle capture. This ensures that the vacuum cleaner not only performs well but also maintains air quality by trapping fine particles.
5. The total power required for the vacuum cleaner was estimated to be around 1.7 kW. This includes the power needed for suction, particle lifting, and overcoming resistance in the filter. The design optimization process effectively balanced

power consumption with performance, resulting in a vacuum cleaner that is both energy-efficient and effective in its cleaning capability.

6. The study underscores the importance of integrating engineering principles such as fluid dynamics, material science, and thermodynamics in the design of household appliances. The approach used in this study can be applied to optimize other domestic cleaning devices, improving their performance and efficiency.

In conclusion, the design and fabrication of the domestic vacuum cleaner achieved the goal of developing an efficient and effective cleaning device through careful consideration of airflow dynamics, particle entrapment mechanisms, and power consumption. The findings of this study provide a solid foundation for future advancements in vacuum cleaner technology and contribute to the broader field of household appliance engineering. The design and material selections were functional but constrained by cost, availability, and weight considerations. The housing was made of thick plywood, with a PVC plastic hose and a 1100 RPM motor. The filter, though efficient, could be improved with a replaceable filter bag and a PVC housing to reduce noise and enhance durability. A wooden base was recommended to dampen vibrations. Additionally, automating the agitator with a motorized roller brush or electric broom could improve performance. These enhancements aim to optimize functionality, durability, and user convenience while maintaining cost-effectiveness

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