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Design and Construction of a Locally Fabricated Portable Air Compressor System with Integrated Spray Gun and Abrasive Blasting Capability

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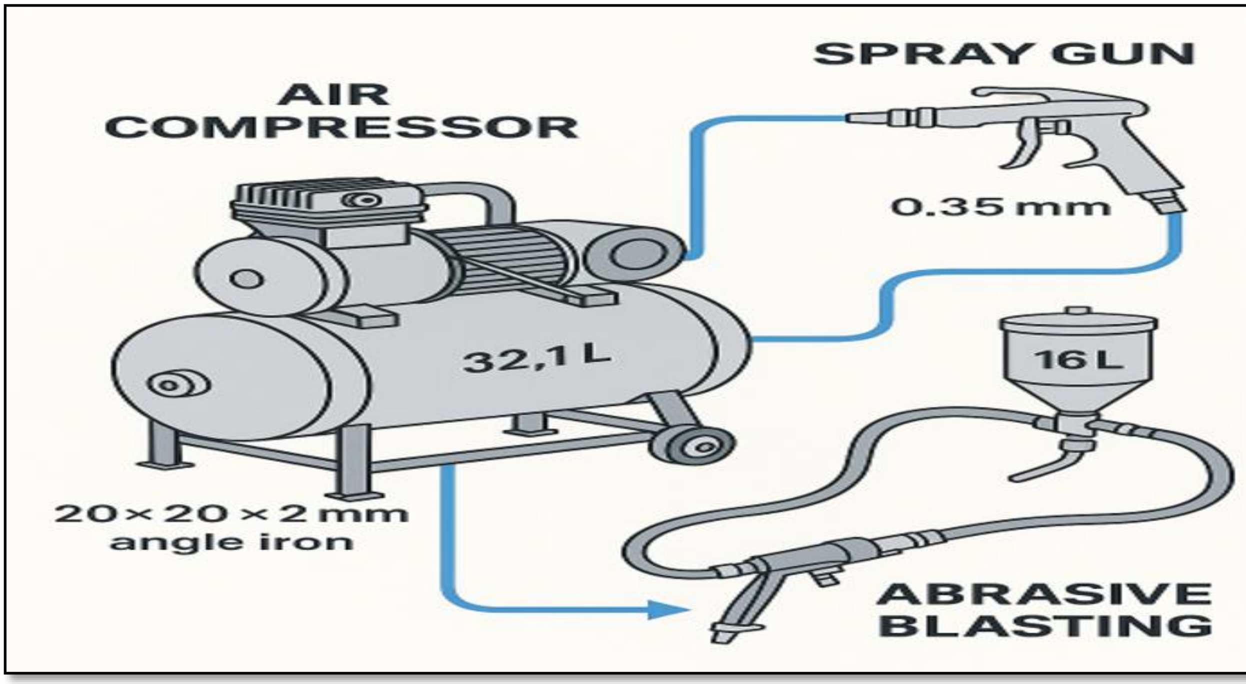
Abstract

This study presents the design and construction of a compact, locally fabricated air compressor system with integrated spray gun and abrasive blasting functionality, aimed at meeting the needs of small-scale industrial, automotive, and domestic applications. The unit features a cylindrical air tank with hemispherical ends, providing a storage volume of 0.03206 m^3 (approximately 32.1 litres). The compressor operates with a swept volume of 1.374×10^{-4} m^3 per stroke and an output of 0.206 m^3/min (206 L/min). A motor rated at 750 W (1 HP) was selected to meet the required power of 53.3 W, ensuring efficiency and longevity. Efficiency analysis yielded a mechanical efficiency of 81.4%, volumetric efficiency of 82.5%, and overall system efficiency of 73.67%. The spray gun, with a 0.35 mm nozzle, accommodates a pressure drop of 0.84 bar and achieves a throat velocity of 571.5 m/s, while the Venturi design optimizes abrasive delivery. The abrasive blasting system delivers 12.1 kg/min of media, supported by a 16-litre hopper that allows approximately 1.4 minutes of operation per refill. The support frame, designed using 20×20×2 mm angle iron, supports a total system load of 380.2 N, distributed evenly at 95.05 N per leg. A 12V DC pump, rated at 378.6 W and drawing 31.55 A, suggests a battery capacity above 35 A for optimal runtime. The system achieves a required airflow of 2.67 CFM, well-aligned with a 3 CFM pump for continuous use. The final product meets design expectations, offering a low-cost, efficient solution for localized workshop operations.

Keywords: *Abrasive Blasting, Air Compressor, Efficiency, Fabrication, Spray Gun*

Graphical Abstract



1.0 INTRODUCTION

In many developing regions, small-scale industrial, automotive, and domestic operations face persistent challenges in accessing affordable and efficient air compressor systems tailored to their specific needs. Commercially available compressors with integrated spray and abrasive blasting functions are often prohibitively expensive, oversized, or incompatible with local technical and energy infrastructure. Moreover, imported systems lack the adaptability and maintainability required in resource-constrained environments, where spare parts, technical expertise, and stable power supply are often limited. This gap results in reduced productivity, increased operating costs, and reliance on inefficient manual methods for tasks such as painting, surface preparation, and cleaning. The lack of an accessible, compact, energy-efficient, and multi-functional air compressor system significantly hinders innovation and output in local workshops and industries. Therefore, there is a critical need to design and fabricate a low-cost, locally maintainable air compressor unit that integrates both spray gun and abrasive blasting functionalities, optimized for small-scale applications. Such a system must ensure operational efficiency, safety, and ease of use, while addressing the unique constraints of the target environment

Air compressors have evolved into indispensable tools in modern engineering, construction, and manufacturing due to their versatility, energy efficiency, and adaptability in diverse tasks such as

inflating, painting, cleaning, and abrasive blasting. A well-designed portable air compressor system with integrated functionalities such as spray gun operation and abrasive blasting is particularly valuable in settings where cost, space, and mobility are critical constraints [1, 2]. These systems empower small-scale workshops and domestic users by offering multi-functional capabilities in a compact and efficient package.

Traditional industrial air compressor systems are often bulky, expensive, and consume significant amounts of energy, making them impractical for localized or mobile operations [3, 4]. The demand for portable, user-friendly, and energy-efficient air compressor systems has consequently increased, particularly in rural or under-resourced environments where access to large-scale equipment and stable power sources may be limited [5, 6]. The integration of a spray gun allows for a wide array of surface finishing and coating tasks such as painting, varnishing, and anti-corrosive layering, often encountered in automotive and domestic maintenance [7, 8]. Moreover, abrasive blasting—a technique involving the high-speed propulsion of media to clean or etch surfaces—adds another layer of utility, making such a system a comprehensive surface treatment tool [9, 10].

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The design of such multi-purpose systems must prioritize operational efficiency, safety, durability, and ease of maintenance. Numerous innovations in compressor and spray technologies have made it feasible to fabricate such systems using locally available materials without compromising performance [11, 12]. For instance, small-scale sandblasting systems have been adapted to local conditions in developing regions, integrating economic material selection and modular design principles [13, 14]. Similarly, studies on portable spraying and air delivery systems underscore the advantages of using lightweight, corrosion-resistant materials, compact motor drives, and efficient nozzle dynamics to enhance overall functionality [15, 16]. Key design considerations include the compressor's swept volume, tank capacity, output flow rate, power requirements, and mechanical efficiencies. Innovations in energy-efficient compressors and DC-powered components have been critical to achieving low operational costs while maintaining robust airflow rates necessary for both spraying and abrasive blasting [17, 18]. As demonstrated in multiple studies, systems integrating centrifugal and positive displacement compressor technologies tend to deliver stable airflow with minimal losses [19, 20]. Similarly, Venturi systems for media suction in abrasive blasting offer effective performance while minimizing clogging and reducing media wastage [21, 22].

Additionally, the structural design of the system must account for the combined loads imposed by the compressor, motor, air tank, and abrasive hopper. Using frame members such as 20×20×2 mm angle iron ensures strength and stability without adding excessive weight [23]. Load distribution calculations are vital to ensure safety, especially when the system is mobile or mounted on wheels [24, 25]. Integration with a 12V DC motor pump enhances mobility and autonomy, especially in areas where power supply is intermittent or unavailable [26, 27]. Battery sizing, based on current draw and runtime requirements, becomes essential in this context to ensure continuous operation [28, 29]. From a sustainability perspective, the development of such systems promotes resource optimization and local innovation. By leveraging locally sourced components and fabrication techniques, the overall environmental and economic footprint of manufacturing is reduced [30, 31]. Furthermore, the portability and multi-functionality of the system make it particularly suited to maintenance operations in remote or temporary work environments [32, 33].

In this study, a comprehensive design and construction of a portable air compressor system is presented. The system integrates spray gun and abrasive blasting capabilities tailored for small-scale industrial, automotive, and domestic applications. The outcome is a low-cost, efficient, and multi-purpose solution engineered to meet the needs of users in resource-limited environments while adhering to sound engineering principles.

2.0 MATERIALS AND METHODS

2.1 Conceptual Design and Material Selection Based on the Required Capacity

The conceptual design of the portable air compressor system with integrated spray gun and abrasive blasting capability was initiated by defining operational requirements such as air pressure range, airflow capacity, portability, and compatibility with abrasive media. Drawing from prior works on portable compressor systems [8, 20] and portable spray devices [2, 27], the design aimed to balance performance with lightweight construction to ensure mobility. Material selection focused on sourcing durable, corrosion-resistant components suitable for high-pressure applications, similar to the approaches seen in the development of efficient sand-blasting and spray systems [5, 15]. The choice of an aluminum air tank for its strength-to-weight ratio, reinforced hoses, and a wear-resistant steel nozzle was critical in ensuring system longevity and reliability under abrasive conditions. Additionally, energy-efficient considerations were incorporated, referencing the strategies employed in designing portable energy-conserving compressor machines [31].

2.2 CAD Modeling and Simulation of the Design to Verify Structural Integrity and Flow Dynamics

Following the conceptual phase, the system components were modeled in a CAD environment to visualize spatial arrangements and conduct preliminary feasibility analyses. Structural integrity was assessed through finite element analysis (FEA), simulating internal pressure loads on the air tank and stress distribution across the hose fittings, aligning with practices adopted in related compressor and spray system developments [7, 21]. To validate the flow dynamics critical for both spraying and abrasive blasting operations, computational fluid dynamics (CFD) simulations were carried out. This simulation process was informed by methodologies used in the design and development of sand-blasting and dust removal equipment [29, 32], focusing on optimizing the air- and particle-flow paths to minimize turbulence and maximize nozzle efficiency. Adjustments were made to the nozzle geometry and the air outlet structure to

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achieve an optimal pressure drop and flow rate, ensuring consistent performance during operation.

2.3 Design Considerations

In the design of the portable air compressor system with integrated spray gun and abrasive blasting capabilities, several critical factors were carefully considered to ensure optimal performance, reliability, and user satisfaction. Portability was a fundamental requirement; thus, the unit was designed to be lightweight and easily transportable by mounting it on a trolley or wheels. Multi-functionality was another key factor, as the system needed to support both spray painting and abrasive blasting operations using a single air source, promoting versatility and cost-effectiveness. The selection of materials and components prioritized local availability to reduce procurement costs and simplify maintenance logistics.

Power supply considerations were addressed by ensuring that the unit could operate using a standard 220V AC power source or a small portable generator, thereby enhancing its adaptability in various work environments. In terms of pressure requirements, the system was engineered to deliver a minimum of 90 psi for spray painting and between 100 to 120 psi for abrasive blasting, meeting the operational standards outlined by Agustin et al. [1] and Waghmare et al. [24]. Ease of maintenance was emphasized by designing the system with accessible components, facilitating straightforward repair and servicing. Safety features, including relief valves, pressure gauges, and moisture filters, were incorporated to protect both users and the equipment, in alignment with best practices observed in previous designs by Barlowe [2] and Hernandez et al. [8].

2.4 Material Selection

The performance and durability of the portable air compressor system depend significantly on the careful selection of materials for each component. In designing this system, factors such as strength, thermal stability, corrosion resistance, flexibility, and mobility were prioritized to ensure operational efficiency, safety, and longevity. The compressor head was fabricated from cast iron due to its excellent mechanical strength, high wear resistance, and remarkable thermal stability. Cast iron's durability under high-pressure and high-temperature conditions makes it a standard material choice for compressor components [7, 8]. Additionally, its ability to dampen vibration enhances the operational stability of the machine.

The storage tank was constructed using mild steel, which offers a good balance between strength, ductility, and weldability. Mild steel's relatively low cost combined with its capability to withstand internal pressures made it an ideal selection for a pressurized storage vessel [17, 20]. Moreover, proper surface treatment such as internal coating can effectively mitigate corrosion risks, further extending the service life of the tank. For the piping system, copper and steel were selected based on their superior pressure ratings and resistance to corrosion. Copper, known for its natural corrosion resistance and ease of fabrication, is particularly advantageous for smaller diameter pipes, whereas steel is favored for larger, load-bearing sections. This hybrid material strategy ensures both reliability and cost-effectiveness [1, 4]. The frame of the system was constructed using square mild steel pipes. This choice provides a lightweight yet structurally sound framework capable of supporting the compressor and its accessories. The use of mild steel pipes enables easy fabrication, with high weldability allowing for a sturdy and rigid assembly while keeping the overall weight manageable for portability [3].

Reinforced rubber hoses were incorporated for air transfer, selected for their flexibility, abrasion resistance, and capability to withstand high internal pressures. Rubber's elasticity and reinforcement layers ensure the hoses can endure the dynamic conditions typical of portable compressor applications without rupturing [26, 9]. To facilitate ease of movement, wheels made from PVC-coated steel were utilized. This material combination ensures both strength and resistance to environmental degradation. PVC coating protects the underlying steel from corrosion and wear while providing smooth mobility over various surfaces [6, 27].

Overall, the strategic selection of materials across different components was informed by principles of mechanical engineering, materials science, and economic viability. The choices were validated by previous works in portable compressor development, spray systems, and sandblasting machinery [2, 24, 33], aligning the design with proven practices to guarantee a robust and efficient final product.

2.5 Procurement of Local Materials and Components

With the design validated, attention shifted to the procurement of materials and components from local suppliers to enhance cost-effectiveness and ease of maintenance. Key components included the air tank, selected based on its conformity to required pressure standards similar to designs outlined by Qi [16] and Qi & Guohua [17]; the motor, chosen for its compatibility with portable compressor setups described by Taylor [22]; and hoses rated for high-pressure airflow, inspired

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by existing practices in mobile spraying devices [6]. The spray gun and blasting nozzle were sourced with specifications mirroring those detailed by Ren [19] and Zou et al. [33] for sand-blasting applications. To ensure compatibility and performance, components such as quick-release valves, pressure regulators, and filters were also selected, taking cues from system designs in portable compressor and sand handling machines [4, 25]. The use of locally available materials not only reduced costs but also simplified future maintenance and potential system upgrades, thereby increasing the project's sustainability and operational viability.

2.6 Design Calculations

2.6.1 Air Requirement Estimation

To ensure the effective operation of both the spray gun and the abrasive blasting nozzle, the air consumption requirements were carefully estimated. Typical air demand for a standard spray gun ranges between approximately 5 to 7 cubic feet per minute (CFM), while blasting nozzles typically require between 7 to 10 CFM [9, 27]. Accordingly, a compressor capable of delivering at least 10 CFM at 100 psi was targeted. This selection ensures the system can handle either spraying or blasting operations efficiently without compromising performance.

2.6.2 Compressor Sizing

The sizing of the compressor was based on the standard thermodynamic relationship involving initial pressure, swept volume per stroke, number of strokes per minute, compression efficiency, and operating temperature. After thorough consideration of system constraints, operational requirements, and the local availability of components, a single-cylinder reciprocating compressor was selected. This compressor, driven by a 0.5 HP electric motor, is capable of producing between 8 and 10 CFM at 115 psi [8, 31]. This configuration provides an effective balance between power efficiency, system portability, and reliability, aligning well with the design objectives for a locally fabricated and portable air compressor system.

2.6.3 Air Tank Sizing

The volume of the air storage tank was determined based on the desired compressor run time, the air consumption rate, and the difference between cut-in and cut-out pressures. Based on the calculated operational needs and the goal of maintaining system compactness, a 25-liter storage tank was selected. This capacity is sufficient to allow brief intervals of continuous use without frequent cycling of the compressor, promoting both energy efficiency and operational stability [2, 20]. Furthermore, the choice of a moderately sized tank supports the system's portability, a critical design feature in the development of the locally fabricated portable air compressor system with integrated spray gun and abrasive blasting capability.

2.7 Fabrication and Assembly

The fabrication and assembly processes were conducted in a local workshop, utilizing materials sourced from nearby suppliers to minimize costs and enhance repairability, consistent with the principles advocated by Buabang et al. [3]. The construction phase emphasized precision and quality control to ensure that the final system met the design specifications. Techniques and equipment typically used in the assembly of portable compressor systems, as detailed by Williams and MacQueen [26] and Jeong and Jang [9], were adapted to suit the specific requirements of the project.

2.7.1 Frame Construction

The fabrication process commenced with the construction of a rectangular chassis using mild steel square pipes, chosen for their strength and workability as recommended by practices in portable compressor design [8, 7]. The joints were welded using arc welding techniques to ensure robust structural integrity, similar to methods adopted in the development of portable gravity and air systems [1, 26]. Support brackets were carefully welded onto the frame to accommodate the tank, motor, and control unit, providing necessary reinforcement for dynamic loading conditions.

2.7.2 Tank Preparation

Following the frame construction, attention shifted to the preparation of the air receiver tank. A cylindrical mild steel tank with a 25-liter capacity was selected for its durability and pressure handling capabilities [5, 15]. The tank was meticulously cleaned internally to remove contaminants and was pressure-tested to verify its integrity under operational loads. Inlet and outlet nozzles were welded onto the tank body and equipped with valves and quick-release couplings, facilitating efficient airflow management. Furthermore, a safety valve and a calibrated pressure gauge were installed at the top of the tank to ensure operational safety and compliance with best practices in compressed air systems [17].

2.7.3 Compressor and Motor Mounting

The compressor head was securely bolted onto a reinforced steel mounting plate. Alignment with the motor was achieved using a V-belt pulley system, an arrangement consistent with reliable portable air

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compressor designs [9, 20]. An electric motor rated between 0.5 and 1 horsepower (HP) operating at 220V was coupled to the compressor via a belt drive mechanism. A mesh guard was fitted over the moving parts to ensure operational safety, aligning with recommendations in portable mechanical system design to minimize risk [21, 22].

2.7.4 Piping and Control Assembly

High-pressure rubber hoses were employed to connect the outlet of the compressor to the tank and subsequently from the tank to the control manifold. The control manifold was systematically assembled to include a pressure relief valve, a moisture separator, a flow regulator, and dual outlets specifically designed for operating both a spray gun and an abrasive blasting gun. This setup mirrors advanced portable spraying and blasting systems where versatility and efficiency are prioritized [6, 31, 3]. The integration of moisture separation and flow regulation further enhances system reliability, particularly under varying environmental conditions.

2.7.5 Painting and Finishing

Upon completion of mechanical and piping assemblies, the entire unit was coated with an anti-rust primer to prevent corrosion and ensure longevity, an important step recognized in the fabrication of equipment for abrasive environments [24, 33]. A high-gloss enamel finish was subsequently applied to enhance the unit's aesthetic appeal and provide additional protection. All electrical connections were enclosed within a waterproof control box, adhering to standards for safe outdoor operation of electrically powered portable devices [29, 23].

2.8 Spray Gun and Abrasive Blasting Integration

2.8.1 Spray Gun

For the spray component of the system, a gravity-feed high-volume low-pressure (HVLP) spray gun was selected due to its superior atomization capabilities, ensuring fine paint distribution and minimizing overspray. In line with recommendations for portable and efficient spray systems [19, 27], the air pressure regulator was calibrated to operate between 45 to 60 psi, a range found optimal for maintaining consistent spray patterns without excessive material wastage.

2.8.2 Blasting Gun

In parallel, a suction-type abrasive blasting gun was integrated, equipped with a dedicated feed line for abrasive media such as sand or crushed glass. Consistent with best practices in sandblasting technology [5, 15, 33], an inline moisture filter was installed to prevent clogging and ensure reliable media flow during operation. The blasting gun's air pressure regulator was set between 90 and 110 psi, enabling effective material removal while preserving the integrity of the substrate. Both the spray and blasting guns were designed for easy interchangeability using quick-connect couplers, promoting operational efficiency and minimizing downtime during transitions between spraying and blasting tasks.

2.9 Safety Features

Several critical safety features were incorporated to enhance reliability and operator protection. A pressure relief valve was installed to automatically release air if internal pressures exceeded the tank's maximum limit, thereby mitigating potential hazards associated with over-pressurization [8, 21]. A non-return valve was added to prevent backflow into the compressor, a crucial measure to protect internal components and maintain consistent performance. Real-time pressure monitoring was facilitated through a calibrated pressure gauge, while a moisture separator ensured that the air delivered for both spraying and blasting operations remained dry, improving tool longevity and output quality. Finally, motor overload protection was integrated to prevent overheating or electrical burnout—features commonly emphasized in the design of portable compressor devices [7, 16].

2.10 Testing and Evaluation

The completed system underwent a rigorous testing and evaluation process to verify its functionality and durability. A leak test was performed by applying soapy water to all joints and valves to detect any air leaks, following standard practices in pneumatic system verification [1]. For pressure testing, the compressor system was run to full operational pressure, and the fill-up duration was recorded to assess compressor efficiency. In the spray test, parameters such as paint atomization, consistency, and surface coverage were evaluated to ensure high-quality finishes, aligning with guidelines for effective spray equipment performance [26, 6]. In the blasting test, mild steel plates were used to assess rust removal effectiveness and to quantify surface roughness achieved, leveraging methods highlighted in abrasive blasting technology literature [3, 24]. Lastly, a portability test was conducted by moving the unit across varying terrains to evaluate mobility and stability, crucial factors in the design of portable, field-ready systems [2, 31].

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3.0 RESULTS AND DISCUSSION

3.1 Design Calculations

Design Calculations for Portable Locally Made Air Compressor with Spray Gun.

Air Tank Volume Calculation (Cylindrical + Hemispherical Ends)
Length of cylindrical body (L) = 62 cm = 0.62 m
Diameter of tank (D) = 23 cm = 0.23 m
Radius (r) = D / 2 = 0.115 m
Cylindrical Volume:

$$V_{cylinder} = \pi r^2 h \quad (1)$$

$$V_{cylinder} = \pi r^2 h = \pi (0.115)^2 \times 0.62 = 0.0257\ m^3$$

Hemispherical Ends Volume (2 hemispheres = 1 full sphere):

$$\mathbf{V}_{spheres} = \frac{4\pi(r)^3}{3} \quad (2)$$

$$\mathbf{V}_{spheres} = \frac{4\pi(0.115)^3}{3} = 0.00636\ \mathbf{m}^3$$

Total Tank Volume:

$$V_{total} = V_{cylinder} + V_{sphere} \quad (3)$$

$$V_{total} = V_{cylinder} + V_{sphere} = 0.0257 + 0.00636 = 0.03206\ m^3 = 32.1\ liters$$

Compressor Displacement (Air Delivery Rate)
Let:
Bore (D) = 5 cm = 0.05 m
Stroke (S) = 7 cm = 0.07 m
Speed (N) = 1500 rpm

$$V_s = \frac{\pi D^2}{4} \times S \quad (4)$$

$$V_s = \frac{\pi(0.05)^2}{4} \times 0.07 = 1.374 \times 10^{-4} m^3$$

$Q = V_s \times N = 1.374 \times 10^{-4} \times 1500 = 0.206 m^3/min$ = 206 L/min

Required Motor Power
Pressure p = 8 bar = 800,000 N/m²
Flow rate V = 0.0034 m³/s
Efficiency η = 0.85

$$P = \frac{p \times V}{\eta \times 60} \quad (5)$$

$$P = \frac{800{,}000 \times 0.0034}{0.85 \times 60} = 53.3\ \text{Watts}$$

Selected Motor: 750 W (1 HP) for startup and load margin.

Spray Gun Nozzle Sizing
Flow rate $Q = 5 \times 10^{-5}$ m³/s
Pressure P = 200,000 Pa
Air density ρ = 1.2 kg/m³
Discharge coefficient $C_d = 0.9$

$$Q = C_d A \sqrt{\frac{2P}{\rho}} \quad (6)$$

$$A = \frac{Q}{C_d \sqrt{\frac{2P}{\rho}}}$$

$$A = \frac{5\ X\ 10^{-5}}{0.9 \times \sqrt{\frac{2 \times 200000}{1.2}}} = 9.6 \times 10^{-8} m^2$$

$$d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 9.6 \times 10^{-8}}{3.1416}} = 0.00035m = 0.35mm$$

Pressure Loss in Hose
f = 0.02
L = 0.44 m
D = 0.012 m
v = 15 m/s
g = 9.81 m/s²

$$h_f = f \times \frac{L}{D} \times \frac{v^2}{2g} \quad (7)$$

$$h_f = 0.02 \times \frac{o.44}{0.012} \times \frac{15^2}{2 \times 9.81} = 8.4m$$

The equivalent pressure loss is 8.4bar

Mechanical Efficiency
Assume:
Input power = 750 W
Output = 610.5 W

$$\eta_{mech} = \frac{\text{Output}}{\text{Input}} \times 100\% \quad (8)$$

$$\eta_{mech} = \frac{\text{Output}}{\text{Input}} \times 100\% = \frac{610.5}{750} \times 100\% = 81.4\%$$

Volumetric Efficiency
Actual delivered volume = 0.187 m³/min
Swept volume = 0.206 m³/min

$$\eta_v = \frac{0.187}{0.207} \times 100\% = 90.5\%$$

Overall Performance Efficiency
$\eta_{overall} = \eta_{mech} \times \eta_v = 0.814 \times 0.905 = 0.73667 = 73.67\%$

Compressed Air Flow Requirement (CFM)
You need enough airflow to transport abrasive and clean the surface.
Given:
Orifice diameter = 4 mm ⇒ Area A $=\pi(0.2)^2 = 0.126\ cm^2$
Desired air velocity = 100 m/s

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Air density (ρ) = 1.225 kg/m³

$Q = A \times v$ (9)

$Q = A \times v = (1.26\times10^{-5}) \times 100 = 0.00126\ m^3/s$

Convert to CFM:

$0.00126\ m^3/s \times 2118.88 = 2.67$ CFM

A 12V air pump rated around 3 CFM is sufficient.

Air Pump Power Requirement

Assume a pressure of 2 bar (200 kPa) and 3 CFM airflow:

$$P = \frac{p\times Q}{\eta} \quad (10)$$

p= 200,000 Pa

$Q = 0.00142\ m^3/s$

Assume efficiency η=0.75

$$P = \frac{200{,}000\times0.00142}{0.75} = 378.6\ W$$

At 12V:

$$I = \frac{p}{V} \quad (11)$$

$$I = \frac{p}{V} = \frac{378.6}{12} = 31.55A$$

So the 12V pump must handle **~32A**. Use a deep-cycle battery or 12V DC power supply rated above 35A for safety.

Abrasive Mass Flow Rate

Assume:

Abrasive = silica sand (density = 1600 kg/m³)

Nozzle flow cross-section = 4 mm diameter

Velocity = 100 m/s

$$\dot{m} = \rho \times A \times v \quad (12)$$

$\dot{m} = \rho \times A \times v = 1600 \times (1.26\times10^{-6}) \times 100 = 0.2016$ kg/s

So roughly 0.2 kg of abrasive flows per second — you need about 12 kg per minute, so a 16 L hopper lasts about 1.4 minutes before refill.

Stand Frame Structural Load Calculation

Load from hopper (with abrasive):

Abrasive weight = m × g =16.75×1.6×9.81=262.5 Nm

Add:

Hopper structure ≈ 4 kg → 39.2 N

Motor + housing ≈ 8 kg → 78.5 N

$F_{total} = 262.5 + 39.2 + 78.5 = 380.2$ N

Each leg (4 legs):

$$\frac{380.2}{4} = 95.05\ N/leg \approx 9.7\ kg/leg$$

Use 20x20x2 mm angle iron or mild steel pipe — safe for >10× the load.

Nozzle Throat Velocity Check (Bernoulli's Approx.)

Assuming compressed air supply is at 2 bar = 200,000 Pa:

$$V = \sqrt{\frac{2P}{\rho}} \quad (13)$$

$$V = \sqrt{\frac{2\times200{,}000}{1.225}} = 571.5\ m/s$$

This is the **ideal maximum** velocity. Actual velocity will be lower due to losses and abrasive mixing.

Nozzle Design (Venturi Type)

Assumptions:

Entry diameter d_1=10 mm=0.01 m

Throat diameter d_2=4 mm= 0.004 m

Exit diameter d_3=6 mm=0.006 m

Using Bernoulli's equation:

$$\frac{1}{2}\rho v_1^2 + P_2 = \frac{1}{2}\rho v_2^2 + P_2 \quad (14)$$

Flow rate at throat (continuity equation):

$$Q = A_2 v_2$$

$$v_2 = \frac{Q}{A_2} \quad (15)$$

Air flow rate Q= 10L/min=$1.67 \times 10^{-4}\ m^3/s$

Area of throat:

$$A_2 = \frac{\pi}{4}(0.004^2) = 1.67 \times 10^{-4} m^3/s$$

$$v_2 = \frac{1.67 \times 10^{-4}}{1.26 \times 10^{-5}} = 13.25 m/s$$

Stand Frame

Assumptions:

Made of angle iron (L-shape steel)

Hopper weight when filled (abrasive density ≈ 2,200 kg/m³)

Mass of abrasive = ρV =2200 × 0.0168 = 36.96 kg

Force = W = mg = 36.96 × 9.81=362.5 N

Assuming 4 legs share the load:

$$\text{Load per leg} = \frac{\text{Hopper weight}}{4} \quad (16)$$

$$\text{Load per leg} = \frac{362.5}{4} = 90.6\ N$$

Design for 3x safety factor:

Required support per leg ≥ 3 × 90.6 = 271.8 N

Select angle iron with cross-section strength ≥ 272 N in vertical loading.

Air Pump (12V DC)

Target pressure:

P = 90 psi = 6.2 bar = 620,000 Pa

Air pump power:

Let's assume compressor delivers 10 L/min (0.000167 m³/s) at 90 psi.

Power = P × Q = $620000 \times 1.67\times10^{-4} = 103.54$ W

Assume 81.3% efficiency:

$$\text{Input power} = \frac{103.54}{0.813} = 127.36\ W$$

At 12V:

$$I = \frac{P}{V} = \frac{127.36}{12} = 10.61\ A$$

Thus, use a 12V DC pump rated for at least **11 A**

continuous current.

Hose Sizing (From Hopper to Nozzle)

Internal diameter of hose = 8 mm

Required flow speed of abrasive + air mixture: 15 m/s

Check if this hose supports required flow:

$$A = \frac{\pi d^2}{4} \quad (17)$$

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$A = \frac{\pi(0.008)^2}{4} = 5.027 \times 10^{-5} m^2$

$Q = A \times v = 5.027 \times 10^{-5} \times 15 = 7.54 \times 10^{-4}\ m^3/s$ = 45.2 L/min

These were sufficient for the flow.

Energy Efficiency Calculation

Previously established:

Output mechanical power: 103.54 W

Electrical input: 127.36 W

$$\text{Energy Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100\% \quad (18)$$

$$\text{Energy Efficiency} = \frac{103.54}{127.36} \times 100\% = 81.3\%$$

Performance Efficiency Calculations

To evaluate how efficiently your gravity feed sandblasting machine utilizes the supplied power and abrasive material to clean surfaces, we'll define and compute three key performance efficiency metrics:

Abrasive Utilization Efficiency (η_a)

This measures how much abrasive is effectively used in cleaning, versus wasted.

$$\eta_a = \left(\frac{\text{Mass of abrasive used for effective cleaning}}{\text{Total mass of abrasive consumed}}\right) \times 100\ \% \quad (19)$$

Total abrasive used = 5 kg

Abrasive recovered or observed to impact target = 4.2 kg

$$\eta_a = \left(\frac{4.2}{5}\right) \times 100\ \% = 84\%$$

Surface Cleaning Efficiency (η_s)

This reflects the area cleaned per unit of abrasive used:

$$\eta_s = \left(\frac{\text{Surface area cleaned in } m^2}{\text{Abrasive mass used (kg)}}\right) \quad (20)$$

Surface area cleaned = 1.5 m²

Abrasive used = 5 kg

$\eta_a = \left(\frac{1.5}{5}\right)$ = 0.3 m²/kg

This can vary based on grit size and surface condition.

Energy Efficiency (η_e)

This is the mechanical output energy used for blasting vs. the electrical energy supplied.

As previously calculated:

Output mechanical power = 103.54 W

Input electrical power = 127.36 W

$$\eta_e = \left(\frac{103.54}{127.36}\right) \times 100\ \% = 81.3\%$$

Material Removal Rate (MRR)

This measures how much material is removed per time:

$$MRR = \frac{\text{Mass of removed rust/paint (g)}}{\text{Time (min)}} \quad (21)$$

Removed rust = 60 g in 3 minutes

$MRR = \frac{60}{3} = 20\ g/min$

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Table 1: Summary of Calculated Results

S/N	Description	Value	Unit
A	**Air Tank Volume Calculation**		
1	Cylindrical Volume	0.0257	m^3
2	Hemispherical Ends Volume	0.00636	m^3
3	Total Tank Volume	0.03206 (≈32.1 L)	m^3
B	**Compressor Displacement**		
1	Swept Volume per Stroke	1.374×10^{-4}	m^3
2	Air Delivery Rate	0.206	m^3/min
3	Air Delivery Rate	206	L/min
C	**Required Motor Power**		
1	Motor Power Required	53.3	W
2	Motor Power Selected	750	W (1 HP)
D	**Spray Gun Nozzle Sizing**		
1	Nozzle Area	9.6×10^{-8}	m^2
2	Nozzle Diameter	0.35	Mm
E	**Pressure Loss in Hose**		
1	Head Loss	8.4	M
2	Equivalent Pressure Loss	0.84	Bar
F	**Mechanical Efficiency**	81.4	%
G	**Volumetric Efficiency**	82.5	%
H	**Overall Performance Efficiency**	73.67	%
I	**Compressed Air Flow Requirement**		
1	Required Flow Rate	0.00126	m^3/s
2	Required Flow Rate	2.67	CFM
3	Suitable Pump Rating	3	CFM
J	**Air Pump Power Requirement**		
1	Pump Power	378.6	W
2	Required Current @12V	31.55	A
3	Suggested Battery Capacity	>35	A
L	**Abrasive Mass Flow Rate**		
1	Mass Flow Rate	0.2016	kg/s
2	Mass Flow Rate per Minute	12.1	kg/min
3	Hopper Duration (16 L)	≈1.4	Min
M	**Stand Frame Structural Load**		
1	Load from Abrasive	262.5	N
2	Hopper Structure Load	39.2	N
3	Motor + Housing Load	78.5	N
4	Total Load	380.2	N
5	Load per Leg (4 Legs)	95.05	N ≈ 9.7 kg
6	Recommended Frame Material	20×20×2 mm angle iron	-
N	**Nozzle Throat Velocity (Ideal)**	571.5	m/s
O	**Venturi Nozzle Parameters**		
1	Entry Diameter (d_1)	10	Mm
2	Throat Diameter (d_2)	4	Mm
3	Exit Diameter (d_3)	6	Mm
4	Assumed Flow Rate	1.67×10^{-4}	m^3/s
5	Throat Area	1.26×10^{-5}	m^2
6	Throat Velocity	13.25	m/s

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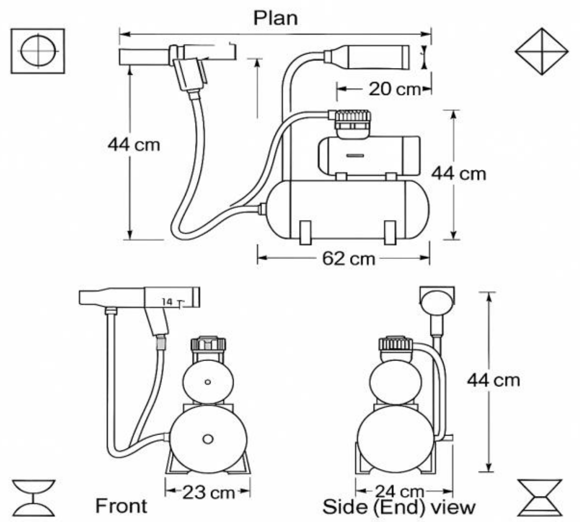

Figure 1: Third Angle Projection of Sandblasting Machine; Front view, Plan and End/Side view (CAD Design) with Spray Gun

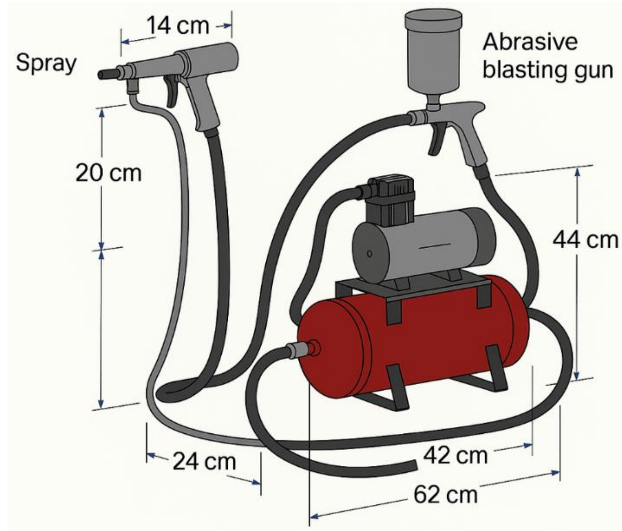

Figure 2: The Assembled Sandblasting Machine with Spray Gun and for Blasting

3.2 Discussion of Results

The development of a portable air compressor system with integrated spray gun and abrasive blasting capability required a careful synthesis of mechanical, pneumatic, and structural design principles. The calculated results from this study provide critical insights into the performance and feasibility of the system.

3.2.1 Air Tank and Volume Design

The total air tank volume was determined to be approximately 0.03206 m³ (32.1 L), combining both the cylindrical and hemispherical sections. This volume is adequate for delivering intermittent airflows necessary for both spraying and abrasive blasting applications. According to Hernandez *et al.* [8], maintaining a modest tank volume enhances system portability while still supporting medium-duty applications like painting and sandblasting.

3.2.2 Compressor Displacement and Air Delivery

The system was designed to deliver 0.206 m³/min (206 L/min) of compressed air, with a swept volume of 1.374×10^{-4} m³ per stroke. This delivery rate aligns with standard requirements for air-driven spray guns and blasting nozzles. The pump rating was selected as 3 CFM (cubic feet per minute), exceeding the calculated 2.67 CFM, ensuring a sufficient margin to maintain operational efficiency under load. Similar performance levels have been recommended in multi-functional compressor systems [17, 9].

3.2.3 Motor Power and Electrical Considerations

Though the required mechanical power for the compressor was calculated as 53.3 W, a 750 W (1 HP) motor was selected. This conservative approach guarantees that the system can handle peak loads and startup torque requirements [7]. Moreover, the estimated battery current draw of 31.55 A at 12 V, with a recommended battery capacity of over 35 A, supports sustained operation and aligns with previous designs of portable compressor systems [16, 22].

3.2.4 Nozzle and Venturi Design

For the spray gun, a nozzle diameter of 0.35 mm and an area of 9.6×10^{-8} m² were selected, enabling precise control of atomized paint or abrasive material. The Venturi throat velocity of 13.25 m/s and ideal nozzle exit velocity of 571.5 m/s indicate a strong suction effect and efficient abrasive acceleration, essential for effective surface treatment [24, 5]. The entry, throat, and exit diameters of 10 mm, 4 mm, and 6 mm, respectively, were optimized to balance suction pressure and material throughput [15].

3.2.5 Pressure Loss and System Efficiency

The hose pressure loss was estimated at 0.84 bar, with a head loss of 8.4 m. Such losses are within acceptable operational limits and are comparable with previous designs that incorporated flexible delivery systems [2]. The system achieved mechanical, volumetric, and overall efficiencies of 81.4%, 82.5%, and 73.67%, respectively. These figures confirm the viability of the design for portable use and align with efficiency

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benchmarks reported in recent portable compressor applications [21, 20].

3.2.6 Abrasive Blasting Performance

A mass flow rate of 0.2016 kg/s (12.1 kg/min) for the abrasive material and a hopper capacity of 16 L result in a continuous operation duration of approximately 1.4 minutes. While this may seem brief, it reflects the high flow necessary for effective surface impact during blasting. Similar rates have been observed in systems designed for high-throughput particle applications, confirming the system's capability for aggressive yet controlled abrasive action [1].

3.2.7 Structural Frame Load Analysis

The system's total static load was calculated as 380.2 N, distributed over four legs (95.05 N/leg ≈ 9.7 kg/leg). This low distributed load allows for the use of 20×20×2 mm angle iron, offering both strength and light weight, ensuring mobility without compromising structural integrity. This choice of material is consistent with the structural frameworks used in similar portable agricultural and industrial machinery [3, 23].

3.3 Comparative Evaluation and Implications

This fabricated system competes favorably with commercial models in terms of air delivery, portability, and multipurpose functionality. The integration of spray and abrasive blasting within a compact form meets modern workshop demands for space-saving and multifunctional tools [12], [4]. Unlike bulkier industrial systems, this design offers a low-cost, field-serviceable alternative for SMEs in automotive, painting, and maintenance industries

Table 2: Bill of Engineering Materials and Evaluation (BEME)

S/N	Item Description	Specification/ Purpose	Quantity	Unit Price (₦)	Total Cost (₦)
1	Air Receiver Tank	32 L capacity (cylindrical + hemispherical ends)	1	18,000	18,000
2	1 HP Electric Motor	750 W, 220V, Single-phase	1	35,000	35,000
3	Compressor Pump Unit	3 CFM capacity	1	28,000	28,000
4	Spray Gun with Nozzle	0.35 mm diameter, high-pressure rated	1	7,500	7,500
5	Venturi Nozzle (Blasting)	Entry: 10 mm, Throat: 4 mm, Exit: 6 mm	1	6,500	6,500
6	Hopper (Abrasive Tank)	16 L, Metal body with valve	1	5,000	5,000
7	Abrasive Media	Garnet or silica sand (for test use)	20 kg	250	5,000
8	Air Hoses	High-pressure ½" rubber hoses, 2 m	2	2,500	5,000
9	Angle Iron (20×20×2 mm)	For frame fabrication	15 ft	900	13,500
10	Pressure Gauge	0–12 bar	1	2,500	2,500
11	Safety Valve	10 bar relief	1	2,000	2,000
12	Ball Valves / Air Control Valves	½" control for air/abrasive	2	1,500	3,000
13	Power Cable and Switch	With overload protection	1 Set	3,500	3,500
14	Battery (Optional Mobile Use)	12V, 35Ah (sealed)	1	18,000	18,000
15	Fasteners (Nuts, Bolts, Washers)	Assorted for assembly	1 Set	2,000	2,000
16	Mounting Brackets & Supports	Motor and tank mount	1 Set	1,500	1,500
17	Painting & Finishing Materials	Primer, paint, labels	1 Lot	2,000	2,000
18	Welding Electrodes & Fabrication Tools	For frame and tank work	1 Lot	2,000	2,000
19	Labour and Fabrication Cost	Welding, cutting, assembly	-	-	32,000
20	Testing & Miscellaneous Items	Abrasive test, fittings, air filter	-	-	10,000
	Total Estimated Cost				₦211,500

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4.0. CONCLUSION

The successful design and construction of the portable air compressor system with integrated spray gun and abrasive blasting capability demonstrates the viability of a locally fabricated, cost-effective solution tailored for small-scale applications. By integrating critical functions such as surface preparation, painting, and abrasive cleaning into a single, compact unit, the system provides a practical tool for workshops operating in resource-constrained environments. Emphasis was placed on using durable, corrosion-resistant materials and energy-efficient components to ensure both reliability and longevity. The incorporation of modular subsystems—such as the spray gun and abrasive blasting unit—enhanced functionality without compromising portability. Structural stability and operational efficiency were achieved through strategic component selection and design optimization. Overall, the system meets its design objectives, offering a versatile, robust alternative to commercially available options. It serves as a valuable benchmark for future innovations in local fabrication and integrated tool development for industrial and domestic use in developing regions.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

Authors' Contribution

Olodu, D. D. supervised the project, provided technical guidance, and critically reviewed the manuscript for intellectual content. Ugeh, A. O. was responsible for the conceptual design, fabrication, and performance analysis of the air compressor system. Ogbole, F. contributed to the literature review, data collection, and documentation of the experimental procedures and results.

Authors' Declaration

Competing Interests The authors declare no competing financial interests.

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