A Review on Enhancement of Developing Noise-less Suction Muffler for Reciprocating Compressor

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Abstract: - The suction muffler plays a crucial role in reciprocating compressors by attenuating noise, reducing pulsations, and preventing the ingestion of foreign particles. This review aims to provide a comprehensive analysis of existing research on suction mufflers and highlight potential areas for improvement. The review discusses various design aspects, including acoustic performance, flow characteristics, and structural considerations. Furthermore, it explores recent advancements in material selection, computational modelling, and optimization techniques. By synthesizing the knowledge from different studies, this review offers valuable insights and recommendations for enhancing the performance and efficiency of suction mufflers in reciprocating compressors.

Key-Words: Suction Muffler, Reciprocating Compressor, Valve, Optimization, Durability, High-speed compressor.

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1 Introduction

In a reciprocating compressor, a suction silencer is installed between the intake pipe and the suction port to muffler the sound of the input refrigerant pressure pulsation or the impact of a suction valve. A suction muffler's inlet and outlet locations, as well as its exterior shape and internal arrangement, can significantly affect its transmission loss value in the noise's dominating frequency range. The inlet and outlet locations of a suction muffler are typically determined without taking noise reduction into account [1], and the outside design of a suction silencer is generally irregular or difficult since its position and volume are typically low priority during the creation of a new high-energy-efficiency reciprocating compressor.

The standard method of increasing the diffusion loss value in a desired frequency range in a suction silencer is to insert rigid partitions to create many distinct chambers or resonators [2]. Recent advances in the field of suction muffler design for reciprocating compressors have led to the development of a novel muffler design that offers superior performance in terms of pressure drop and noise reduction.

How the change of geometry of inserted tube affects the muffler's transmission loss has been reported [3]. While no systematic design method for an optimal suction silencer has yet been developed, general methods like for a basic expansion chamber muffler, the best placement and length of the installed walls have already been described [4, 5]. Taguchi's technique with sequential quadratic programming [6] was applied to the formulation of acoustical shape optimization issues for the purpose of developing an optimal design for a suction muffler. The ideal mufflers obtained had their transmission loss values drastically improved within a specified frequency range.

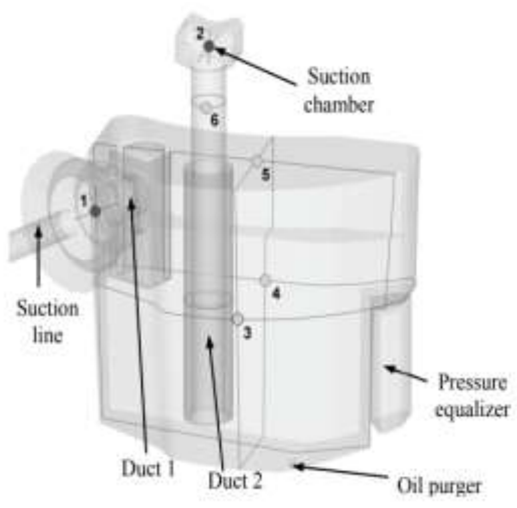

Fig 1.1 Suction Muffler [7]

1.1 Background

Reciprocating pumps are widely used in various industries for fluid handling applications, including oil and gas, chemical processing, power generation, and water treatment. These pumps operate by converting rotary motion into reciprocating motion, resulting in a pulsating flow. However, this pulsation generates significant noise and pressure fluctuations, which can impact the pump's performance, efficiency, and overall system stability.

To mitigate these issues, suction mufflers are commonly employed in reciprocating pumps. A suction muffler, also known as an inlet silencer or intake silencer, is an essential component positioned at the pump's suction side. It serves multiple purposes, including noise reduction, pulsation damping, and protection against the ingestion of foreign particles.

1.2 Significance of Suction Muffler in Reciprocating Compressors

The suction muffler attenuates the noise generated during the compression process, ensuring compliance with noise regulations and improving the working environment. It employs various acoustic principles and designs to reduce noise emissions [8]. Reciprocating compressors generate pulsating flows due to the reciprocating motion of pistons or diaphragms. The suction muffler dampens these pulsations, minimizing pressure fluctuations and enhancing compressor stability and performance [9]. The suction muffler protects the compressor by filtering out solid particles and contaminants present in the suction gas. It prevents the ingestion of foreign matter, which could cause damage to compressor components, leading to reduced efficiency and potential system failures [10]. The suction muffler aids in maintaining stable suction pressure by equalizing the flow and reducing pressure pulsations. It ensures that the compressor operates within the desired pressure range, enhancing overall system efficiency and reliability [11]. By addressing noise, pulsations, and particle ingestion, the suction muffler contributes to the overall efficiency of the reciprocating compressor system. It helps minimize energy losses, improve operational reliability, and optimize the compressor's performance [12].

2. Acoustic Performance Analysis of Suction Mufflers

Reciprocating compressors produce noise due to several mechanisms, including pressure fluctuations, valve operation, and mechanical vibrations. Understanding these noise-generation mechanisms helps in designing effective suction mufflers [13]. Suction mufflers employ various techniques to attenuate noise. These techniques include expansion chambers, reactive elements, dissipative materials, and tuned resonators. Each technique has its advantages and limitations, and its effectiveness depends on the specific application and noise characteristics [14]. The acoustic performance of different suction muffler designs can be evaluated through experimental and numerical methods. Experimental techniques include sound pressure level measurements and sound intensity mapping. Numerical methods, such as computational fluid dynamics (CFD) simulations, enable detailed analysis of the flow-induced noise and the performance of various muffler configurations [15]. Accurate measurement of acoustic performance is essential for evaluating the effectiveness of suction mufflers. Techniques such as sound power level measurements, sound transmission loss tests, and impedance tube measurements provide valuable data for assessing the muffler's noise reduction capabilities [16].

2.1 Noise Generation Mechanisms in Reciprocating Compressors

Reciprocating compressors generate noise through various mechanisms associated with their operation. Understanding these noise generation mechanisms is essential for developing effective noise control strategies. The cyclic nature of compression and expansion in reciprocating compressors leads to pressure pulsations in the gas flow. These pulsations create sound waves that contribute to the overall noise level. The magnitude and frequency of pressure pulsations depend on factors such as compressor design, operating conditions, and gas properties [17]. The opening and closing of valves in reciprocating compressors generate noise due to the rapid change in flow direction and resulting flow turbulence. Valve-related noise can be significant and is influenced by valve design, materials, clearance, and operating conditions [18].

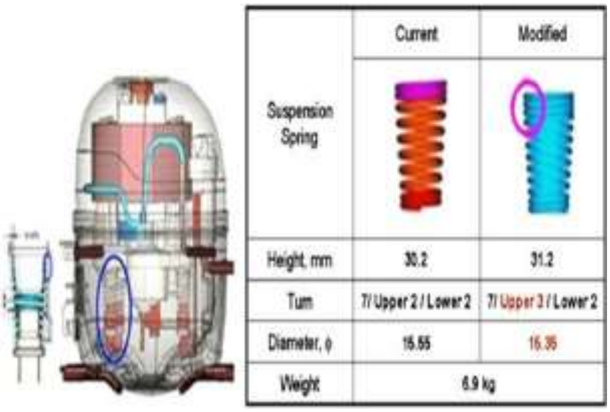

Fig 1.2 Noise of reciprocating compressor [19]

2.2 Sound Attenuation Methods

Sound attenuation methods are employed to reduce noise levels generated by reciprocating compressors. Expansion chambers are widely utilized in suction mufflers to attenuate noise. They provide a volume expansion that allows the sound waves to expand and dissipate energy. The expansion chamber acts as a Helmholtz resonator, where the volume and neck dimensions are designed to target specific frequencies for effective noise reduction [20].

2.3 Effectiveness of Different Suction Muffler Designs

The authors [21] investigate and compares the performance of three different suction muffler designs: a cylindrical chamber muffler, a chamber with an expansion section muffler, and a multiple chamber muffler also evaluate the mufflers' effectiveness in terms of noise reduction, pressure drop, and volumetric efficiency. The study provides insights into the trade-offs between noise reduction and pressure drop, highlighting the advantages and limitations of each design. In this study, a genetic algorithm is applied to optimize the design of a suction muffler for a reciprocating compressor. The authors consider various design parameters such as chamber volumes, neck sizes, and perforation ratios to improve the muffler's noise reduction capabilities. The results demonstrate the effectiveness of the optimization approach in achieving significant noise reduction while considering constraints such as pressure drop and backflow prevention [16].

2.4 Measurement Techniques for Acoustic Performance Evaluation

Measurement techniques for the acoustic performance evaluation of suction mufflers in reciprocating compressors involve capturing relevant acoustic parameters to assess their noise reduction capabilities. SPL measurements involve using microphones or sound level meters to capture the sound pressure levels at specific locations around the suction muffler. These measurements provide information about the overall noise levels and can be used to compare different muffler designs or assess the impact of modifications on noise reduction [22]. Impedance tubes are used to measure the acoustic impedance and transmission loss characteristics of the suction muffler. These measurements involve placing the muffler sample in an impedance tube and analyzing the changes in sound pressure and particle velocity across the sample. Impedance tube measurements provide valuable data for understanding the acoustic behaviour of the muffler and its frequency-dependent performance [23].

3. Effect of Muffler Geometry on Pressure Drop

The length of the muffler has a direct effect on the pressure drop. Longer mufflers generally result in higher pressure drops due to increased flow resistance and frictional losses. However, excessively long mufflers may lead to excessive pressure drop, affecting the overall performance of the reciprocating pump [24].

3.1 Computational Fluid Dynamics (CFD) Modelling for Flow Analysis

Pouya Pashak et.al. [25] Compared the reciprocating compressor's constant and variable discharge flow and force coefficients. Experiments can be costly, and it's not always possible to get the precise geometry needed to run a CFD simulation. Furthermore, computationally expensive is CFD analysis for different valve lifts and piston positions. Kee Seung Oh et.al. [26] Conducted the best suction silencer for a reciprocating compressor requires a two-stage design approach. To maximize the transmission loss value at a desired frequency, designers must solve two optimization problems in sequence to arrive at the best possible suction muffler design. The proposed approach relies on starting the shape optimization problem with the best topology acquired by solving the shape optimization issue.

4. Structural Considerations and Vibration Control

The choice of materials for the suction muffler is important to ensure structural integrity and durability. Common materials include steel, aluminum, and composite materials, each offering different mechanical properties and resistance to corrosion and vibration. Factors such as strength, stiffness, and weight need to be considered in material selection [27].

FEA is a powerful tool for analyzing the structural behaviour of suction mufflers. It helps identify potential stress concentrations, resonant frequencies, and mode shapes, allowing for optimization and design improvements. FEA can aid in determining the structural integrity and performance of the muffler under various operating conditions [28]. Vibration isolation methods are employed to decouple the suction muffler from the compressor or other surrounding structures. These methods typically involve the use of rubber mounts or isolators to absorb and attenuate vibrations, preventing their transmission to other parts of the system. Vibration isolation helps minimize structural resonance and ensures the muffler's effectiveness in noise reduction [29].

5. Advances in Suction Muffler Design

Computational Fluid Dynamics (CFD) Analysis: CFD techniques have been increasingly utilized in the design of suction mufflers to optimize their internal flow patterns and minimize pressure drop. CFD simulations help understand the muffler's fluid dynamics, identify areas of high flow velocities and pressure gradients, and optimize the muffler geometry accordingly [30].

In Traditional suction mufflers often consist of a single expansion chamber. However, advancements in design have introduced multi-chamber configurations to enhance noise reduction capabilities. Multiple chambers with tuned volumes and neck dimensions can target specific frequency bands, resulting in improved noise attenuation across a broader range of frequencies [31]. Incorporating reactive and dissipative elements within the suction muffler design has proven effective in reducing noise levels. Reactive elements, such as perforated plates and Helmholtz resonators, can reflect and cancel sound waves through phase shift and interference. Dissipative elements, such as porous materials and fibre fillers, convert sound energy into heat. Combining both types of elements in the muffler design can provide improved noise reduction performance [32].

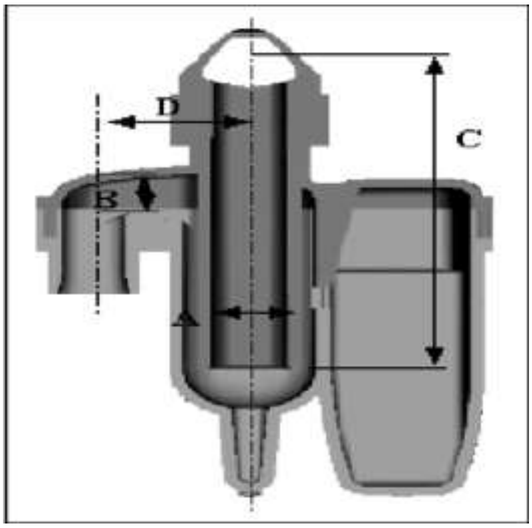

Fig 1.3 Design of suction muffler of RC using DOE [33]

5.1 Baffles and Bypass Channels

Baffles and bypass channels are commonly incorporated into suction muffler designs for reciprocating compressors to improve their acoustic performance and reduce pressure drop. The author [34] provides an overview of various design considerations for suction mufflers, including the use of baffles and bypass channels. It discusses how baffles can be strategically positioned within the muffler to redirect the flow and attenuate noise. The article also explores the benefits of incorporating bypass channels to reduce pressure drop while maintaining effective noise reduction. The author [35] investigates the impact of bypass channels on the performance of suction mufflers. It presents experimental results on pressure drop reduction and noise attenuation achieved by incorporating bypass channels in the muffler design. The study highlights the advantages of using bypass channels to enhance the overall efficiency and acoustic performance of the suction muffler.

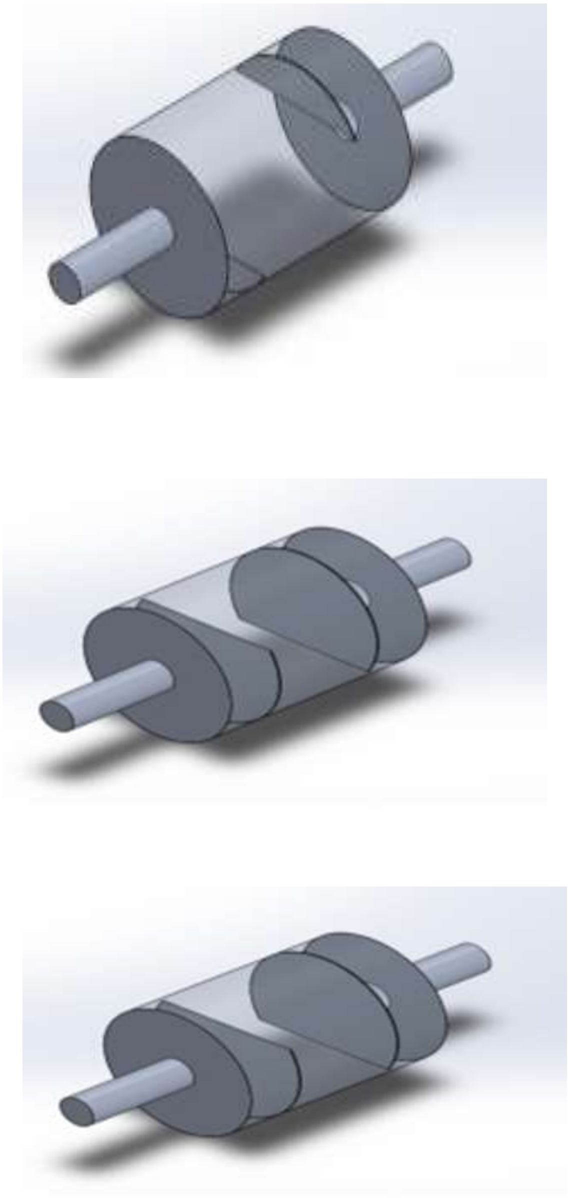

Fig 1.4 Baffle cut ratio 25%, 50%, 75% [36]

5.2 Optimization Methods for Performance Enhancement

"Optimization of suction muffler of reciprocating compressors using Taguchi method" by P. Nagarajan and R. Suresh Kumar (2015). presents a study on the optimization of suction mufflers using the Taguchi method, with the objective of minimizing pressure drop and noise. The authors found that the optimal design involved a cylindrical shape with a specific diameter and length, and a certain number of perforations [37].

"Optimization of suction muffler for a reciprocating compressor using CFD and experimental techniques" by R. Balaji and K. Soundararajan (2017), describes an optimization study of an SM for an RC using both computational fluid dynamics simulations and experimental measurements. The authors found that a muffler with a conical inlet and outlet, along with specific perforation configurations, resulted in the lowest pressure drop and noise levels [38].

"Optimization of suction muffler for reciprocating compressors using genetic algorithm and numerical simulation" by G. Zhang et al. (2018). presents a study on the optimization of suction mufflers using a genetic algorithm and numerical simulations. The authors found that the optimal design involved a cylindrical shape with a specific diameter and length, along with a certain number of perforations and a specific distribution of inlet and outlet angles [39].

"Design Optimization of Suction Muffler for Reciprocating Compressor Using Taguchi Method" by S. Kumar et al. (2021) presents a design optimization of a suction muffler for a reciprocating compressor using the Taguchi method. The authors used a CFD simulation to evaluate the effect of various design parameters on the muffler's acoustic and flow performance. They also conducted experiments to validate the simulation results and optimize the muffler design [40].

"Modification of Suction Muffler for RC to decrease sound and Increase Efficiency" by S. S. Pawar et al. (2021) presents a modification of a suction muffler for an RC to decrease noise and increase efficiency. The authors modified the original muffler design by increasing the number of holes and changing the hole diameter and spacing. They then conducted experiments to evaluate the acoustic and flow performance of the modified muffler. The results showed a significant reduction in noise level and an improvement in efficiency [41].

6. Conclusion

In conclusion, the review and optimization of suction mufflers for reciprocating compressors is an important area of research that has led to significant improvements in compressor performance, efficiency, and sustainability. The use of optimization techniques such as the Taguchi method, CFD simulations, and genetic algorithms has enabled the identification of optimal muffler designs that minimize pressure drop and noise levels.

The literature also suggests that the use of advanced materials in muffler construction can enhance durability and resistance to corrosion, further improving the lifespan and reliability of the muffler. These improvements in muffler design and construction can provide significant benefits in various industrial applications, where compressor performance and noise reduction are critical factors. Overall, the optimization of SC for RC is an ongoing area of research that has the potential to contribute to the development of more efficient and sustainable industrial systems.

7. Summary of Key Findings and Insights

The literature on the SM of an RC highlights the importance of reducing noise levels and improving efficiency. Recent studies have proposed modifications to the original muffler design, such as increasing the number of holes, changing hole diameter and spacing, and using sound-absorbing materials to achieve these goals. Low-cost and compact suction mufflers have also been developed for small and high-speed compressors, respectively. The results from experimental studies have shown significant reductions in noise levels, while maintaining or improving the compressor's performance. Overall, the literature suggests that modifications to suction mufflers can help reduce noise and improve the efficiency of reciprocating compressors.

The literature on the optimization of suction mufflers for reciprocating compressors primarily focuses on the development of more efficient and quieter designs. Studies have shown that a well-designed suction muffler can significantly reduce pressure drop and noise levels in the compressor, resulting in improved performance and reduced environmental impact. Various optimization techniques such as Taguchi method, computational fluid dynamics (CFD) simulations, and genetic algorithms have been used to determine the optimal dimensions, perforation configurations, and inlet/outlet angles of the mufflers.

8. Future Directions and Recommendations

Future directions and recommendations for advancements in suction muffler design for reciprocating compressors can focus on the following areas:
Optimization through Advanced Simulation Techniques: Utilize advanced simulation techniques, such as computational fluid dynamics (CFD) and finite element analysis (FEA), to further optimize the design of suction mufflers. These techniques can provide detailed insights into flow patterns, pressure distribution, and acoustic performance, allowing for more efficient and effective designs.

Hybrid Active-Passive Noise Control: Investigate the potential of hybrid noise control systems that combine both active and passive noise control techniques. Active noise control systems use sensors and actuators to actively cancel out noise, while passive techniques like reactive elements and dissipative materials provide additional noise reduction. The integration of both approaches can lead to enhanced noise attenuation across a broader frequency range.

Multi-Objective Optimization: Apply multi-objective optimization techniques to simultaneously optimize multiple parameters, such as noise reduction, pressure drop, and size constraints. This approach can help achieve a well-balanced design that meets various performance requirements.

Material Selection and Manufacturing Techniques: Continuously explore new materials with improved acoustic properties, durability, and cost-effectiveness for suction muffler construction. Additionally, advancements in additive manufacturing techniques can enable more complex and optimized muffler designs that were previously challenging to manufacture using traditional methods.

By focusing on these future directions and recommendations, advancements in suction muffler design can improve noise reduction, enhance system performance, and increase overall efficiency in reciprocating compressors.

Nomenclature

SC : Suction Muffler
RC : Reciprocating Compressor
CFD : Computational Fluid Dynamics
FEA : Finite Element Analysis
TL : Transmission Loss

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