Cairo University

Design and Modeling of Diesel Engine Spark Arrestor with Experimental Verifications

By

Eng. Mohamed Mostafa Mohamed Farid Ammar

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
MECHANICAL DESIGN AND PRODUCTION ENGINEERING

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Keywords:
Spark arrestor; Ember; Fire, Explosion; Automotive; Diesel Engine

Summary:

All diesel engines produce exhaust carbon particles. These particles are originated from the carbon deposition formed on the internal surfaces of the exhaust system and the engine. Then they may be expelled at high temperature to the atmosphere. Particles diameter larger than 0.58 mm and at temperature 649^{o}C could ignite flammable materials upon contact, so Spark Arrestor plays critical role in impeding the embers emission as it is a device that arrests the embers and the sparks.

The aim of this study is to make theoretical modeling and experimental verification to compare between two new models of diesel engine Spark Arrestors and a commercial Spark Arrestor in terms of the collection efficiency and acoustics.

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Nomenclature

A	Cross sectional area
c	Sound speed
C.E.	Collection Efficiency
$\boldsymbol{D_H}$	Hydraulic diameter
d	Pipe diameter
$\mathbf{F_D}$	Drag force
$\mathbf{F_g}$	Gravitational force vector
$\mathbf{F_{ext}}$	External force
f	Frequency
g	Gravity vector
$\mathbf{h_e}$	Head loss
IL	Sound Insertion Loss
k	Turbulent kinetic energy
$\boldsymbol{k_e}$	Loss coefficient
$\boldsymbol{k}$	Wave number
L	Length
M	Mach number
$\mathbf{m_p}$	Particle mass
P	Stagnation pressure
$\mathbf{P_s}$	Fluid static pressure
$\boldsymbol{p}$	Acoustic pressure
$\mathbf{p^s}$	Source pressure
$\mathbf{P_k}$	Net production per unit dissipation of k
Q	Volumatric flow rate
$\boldsymbol{q}$	Acoustic Volume velocity
$\mathbf{q^s}$	Source volume velocity
Re	Reynolds number
$\mathbf{R}_f$	Flow resistance
$\mathbf{S_m}$	Scattering matrix
SPL	Sound pressure level
$\mathbf{T_{ij}}$	Element of the two port transfer matrix
TL	Sound Transmission Loss
u	Particle Velocity
u', v', w'	Fluctuation velocity components in x, y, z directions
v	Fluid velocity

W	Width
μ	Fluid dynamic viscosity
ν	Kinematic viscosity
ρ	Fluid density
ω	The specific dissipation rate
ε	Turbulence dissipation
$\boldsymbol{\mu_T}$	The eddy viscosity
α, β, β*, σ, σ*	Model constants
$\boldsymbol{\tau_p}$	Particle velocity response time
$\boldsymbol{\rho_p}$	Particle density
ω	Angular frequency
λ	Wave length

Abstract

The sparks and embers which are produced from combustion sources could lead to fire and explosions as a result of ignition of flammable materials which are exposed to these emissions. There are many sources of combustion that produce embers such as internal combustion engines, wood burning stoves, steel mill, cement plant,...........etc, so Spark Arrestor plays critical role in impeding the embers emission as it is a device that arrests the embers and the sparks.

The aim of this study is to make theoretical modeling and experimental verification to compare between two new Prototypes of Diesel Engine spark arrestor and a commercial spark arrestor in terms of collection efficiency, acoustics, pressure drop, and cost.

COMSOL software using finite element is used to model the collection efficiency while SIDLAB using two-port theory is used to model the acoustic characteristics.

The two new Prototypes A and B were manufactured and tested to verify experimentally the theoretical modeling through the different test rigs. Three different flow rates were selected for the experimental verifications.

On the other hand, the three Spark Arrestors were experimented on a real diesel engine of 32 KW.

The theoretical models of collection efficiency were shown to be matched with the experimental verifications for Prototype A within 98.8%, Prototype B within 92.5%, and the commercial spark arrestor within 89.4%.

While the theoretical models of transmission loss were shown to be matched with the experimental verifications for Prototype A within 95.2%, Prototype B within 70%, and the commercial spark arrestor within 83%.

And the theoretical models of pressure drop were shown to be matched with the experimental verifications for Prototype A within 93.75%, Prototype B within 98.27%, and the commercial spark arrestor within 90%.

The three spark arrestors were experimented on real diesel engine at different loads in compliance with ISO 8528-10 for diesel engine generators. Complete arrest for sparks were shown during the period of the experiment and the insertion loss measured ranges from 5.3 to 13.5 dB.

According to the theoretical modeling and measurement results in terms of collection efficiency, acoustic performance, and pressure drop of the three Spark Arrestors and their cost, the Spark Arrestor Prototype B was shown to have the best performance.

Chapter 1: Introduction

1.1. Preamble

Fire and Explosion have serious effect on business, economy, and life. Inefficient design, inadequate maintenance and understanding of risks may be a result of fire and explosion, [1].

Companies which use flammable materials shall put in its account the fire safety. For example in petroleum companies the flash point of their substances shall be known and put in safety environment. The flash point helps in knowing the maximum temperature that these substances may be exposed without causing fire.

This work focus on Spark Arrestors' design (collection efficiency and acoustics performance), in the field of diesel engines as Spark Arrestor is part of the exhaust system.

Spark Arrestors are installed at locations where sparks may be dangerous to the surrounding environment, [1].They are provided on the exhaust of source or fire where a hot particulate might be released (i.e., internal combustion engines, chimneys, incinerator stacks, etc.).

Spark Arrestor is used to prevent the risk of fire due to the burning of flammable materials caused by sparks emission from diesel engine exhausts, [2].As Spark Arrestor is a device traping exhaust carbon particles to a size below 0.58 mm in diameter. If particles larger than 0.58 mm in diameter and at temperatures of 649°C are expelled then it will be capable of igniting cellulose materials upon contact, [3].

Spark Arrestor is made from stainless steel, carbon steel, or aluminized steel as aluminized steel is used to resist heat, corrosive gases, and to extend service life of arrestor, [4].

Spark Arrestor place in most of engines is in exhaust manifold where the exhaust from each cylinder of the engine is collected. Then the exhaust flows out of the manifold to a spark Arrestor or muffler or both, [3].

The Spark Arrestor inclined more than 60 degrees from its efficient operating position may not arrest sparks adequately. As the United States Department of Agriculture (USDA) Forest Service Standard 5100-1c allows 60 degrees deviation, but at least 15 degrees should be reserved for deviations because of road grade or slope, [3].

Spark Arrestors shall have a method for removing the cumulative carbon particles such as a cleanout plug, removable end cap, snap ring or a removable end cleanout, [3].