Review of Acoustics Technology for Cleaning at Industries

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Abstract

Acoustics can primarily be defined as the discipline that deals with the creation, reception, transmission, control, and properties of sound, where mechanical waves propagate in an elastic medium such as solids, gases, and liquids. Such mechanical waves transfer energy from one point to another without inducing permanent displacement on the medium. As such, waves do not transfer mass but energy, therefore, mass is only moved perpendicular in the direction of propagation. Based on the scientific principles of acoustics technology, many industrial plants have adopted this form of technology for internal substructure cleaning methodologies of plant equipment. This form of cleaning methodology is known as either acoustic cleaning or sonic cleaning. An acoustic cleaning device is utilized to inhibit particulate material accumulation on various plant equipment such as boiler units, ducts, hoppers, and electrostatic precipitators. Surface cleanliness is maintained without intrusion into the internal substructure of plant equipment. This paper reports on the state or arts in the development of the acoustics cleaning technology.

Keywords
Acoustics Technology, Acoustic Horn, Sound

1. Introduction

A power plant is an industrial facility that burns fossil fuels such as coal, oil, and natural gas for the generation of electrical power. Moreover, a power plant is also referred to as a power station or powerhouse. A typical power station configuration comprises of the following components namely, a generator, steam turbine, condenser, feed water pump, and boiler unit(s). The electricity production process commences with pulverized coal fed from a mill into a boiler that induces heat and as a result, the coal particles combust and burn to generate heat that converts water into steam by means of convection heat transfer.

The steam generated from the boiler turns the turbine blades at very high speeds, as a result, the turbine rotates the rotor encased in a stator (these are the sub-components that make up the generator). Ultimately, the generator produces an electric current, which is transmitted to end users such as industrial areas and households via power lines, Figure 1.

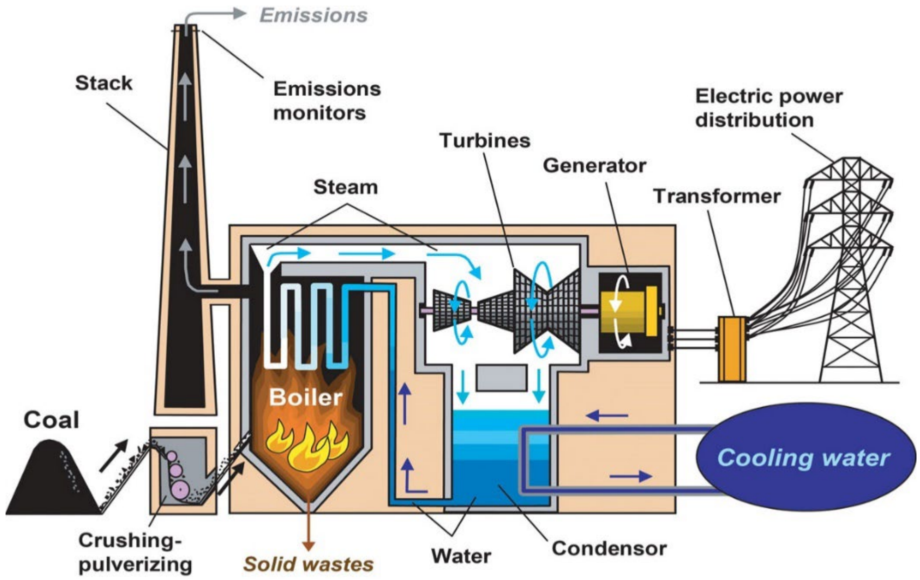

Figure 1. Power plant diagram (Rudy, 2019).

Operational efficiency of a power plant relies on the full optimization of each component. Unfortunately, adverse outcomes such as steam turbine vibration failures, generator faults, and boiler inconsistencies occur periodically. Boilers are often prone to a number of inconsistencies such as tube erosion, low boiler pressure, ash agglomeration, slagging, obnoxious odor, corrosive embrittlement, fatigue failure, and excessive temperature erosion.

Sasol Synfuels power station situated in Secunda, Mpumalanga province of South Africa experiences slag agglomeration on their boiler tubes that are a result of ash produced from burning coal in the boilers (Shandu et al, 2019). The slag agglomeration presents a condition that requires more fuel to be used in order to attain the same temperature and output as with a clean boiler. This is due to the slag agglomeration acting as an insulation layer that shields the boiler tubes from the heat in the boiler chamber (Justin, 2014).

Therefore, this inhibits optimal operation of the power plant rendering it a necessity to clean boilers. Sasol currently employs water lances and soot blowers cleaning methodologies (Shandu and Kallon, 2021. A water lance is a manual maintenance procedure in which high pressure water jets are used to clean the boiler interior. While soot blowers make use of compressed fluids such as water, air, or steam to prevent slag agglomeration.

The disadvantages of soot blowers cleaning methodologies are that a boiler shutdown is generally required and tube erosion may occur as a result of implementing water lances and soot blowers (Shandu et al, 2020a; Shandu et al, 2020b). Amongst other available cleaning techniques, there is a none intrusive cleaning methodology that deploys sound waves, known as the acoustic cleaning system.

An acoustic cleaner is a pneumatically activated sonic horn that produces low frequency, high energy sound waves that render particulate matter that have bonded onto surfaces to reverberate and extricate from these surfaces. Once displaced, the particulate matter is detached by gravity as micro-particles (Primasonics Acoustic Cleaners, 2019).

Sound waves generated by the acoustic cleaner device incur excessive vibration signals that may compromise the structural integrity of the boiler sub-components. In order to prevent this undesirable effect, a vibration sensor and a control system have to be integrated into the system to preserve the boiler and aid in improving the plant's productivity.

Sensors actively measure physical properties (to name a few; temperature, pressure, acceleration, position, vibration) and provide feedback for signal processing or signals that can be utilized by a control system to regulate the process through transforming input forces and movement into the desired output (Donna, 2019). A control system enables the amplification to gain control of the controlled variable as intended by the user. It can also account for disturbance rejection experienced by the system and facilitate remote control (Wayne, 2002).

2. Acoustics Cleaning Technology

2.1. Acoustics

Acoustics can primarily be defined as the discipline that deals with the creation, reception, transmission, control, and properties of sound. Acoustics in itself entails an immense array of subjects that include; noise control, architectural spaces, thermoacoustic refrigeration, bioacoustics, SONAR for submarine navigation, seismology, electroacoustic communication, medical imaging ultrasounds, and the study of musical instruments (Physics and Astronomy, 2019).

Acoustics also has a subdivision of technology that deals with part of humanity to alter the environment in order to make lifestyles intriguing and gratifying (Truax, 1984). The acoustics scientific philosophies have been variously applied on human civilization, such as the music industry. The capability of recording and reproducing sound has created the music industry that has brought the liking of music to millions of people. Finally, acoustics does not only deal with science and technology, but is also viewed as art. This is observed by millions of people who have shown its concern for music, out of which undeniably the science of acoustics established and whose connotation with methodical sound quality is growing ever more rapidly (Lindsay, 1973).

2.1.1. Acoustics Fundamentals

Acoustics proves to be an extensive field of study, therefore; this review only discusses the science and technological domains of it. By definition, acoustics is concerned with the study of sound (mechanical waves) in an elastic medium such as solids, gases, and liquids. Sound creates atmospheric pressure fluctuations and is the result of pressure variations and oscillations generated by a turbulent fluid flow and vibrating surfaces. Sound proliferates in the form of longitudinal waves comprising a sequence of compressions and rarefactions induced in the elastic medium.

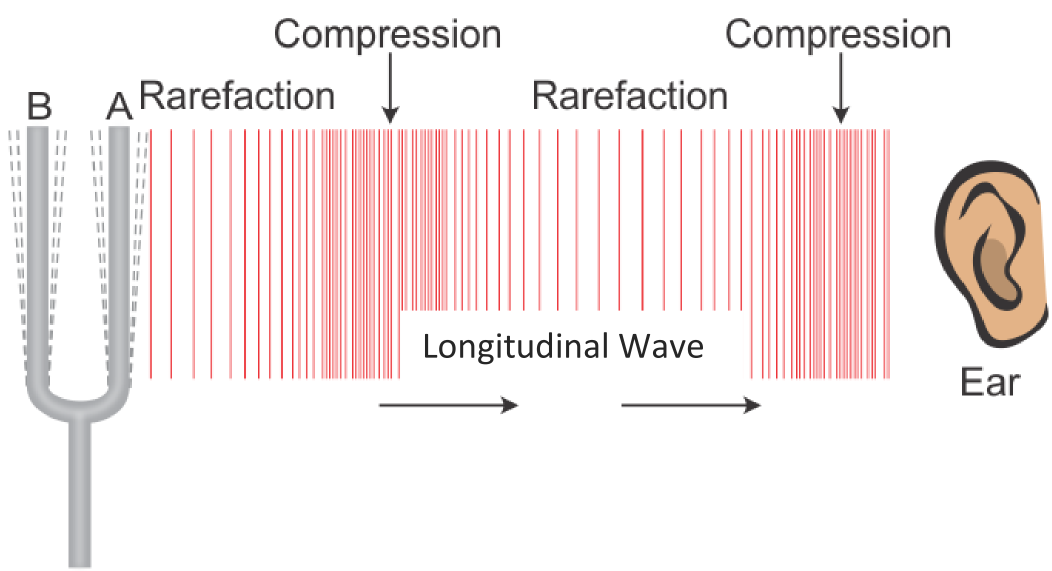

Figure 2. Compressions and rarefactions as a result of a sound wave (Topper Learning, 2015).

Figure 2 denotes a simple illustration of sound waves propagating in air by making use of a tuning fork that vibrates to produce sound in which the pressure variations are below and above the ambient atmospheric pressure. The air layers around the sound source vibrate in the same way and carry sound waves of alternating rarefactions and compressions in air from the sound generating object to the receiver (in this case the ear). Rarefactions are defined as regions where atoms are spread apart, while compressions are regions where atoms are close together (NCVP, 2016).

2.1.2. Sound Waves

In general, a wave is an oscillation that travels through space and time supplemented by a transfer of energy. The energy transferred as a result of waves from one point to another is without permanent displacement of particles on the medium. This is due to the fact that waves do not transfer mass but energy. Mass is only moved perpendicular in the direction of propagation. Figures 3 and 4 facilitate a simple illustration of how mass travels in an ocean wave.

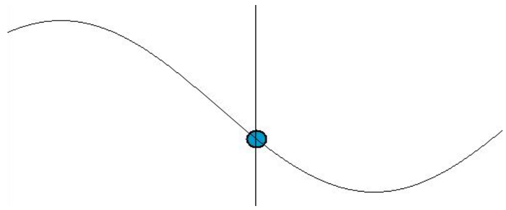

Figure 3. Wave motion (mass down) (Lumen Learning).

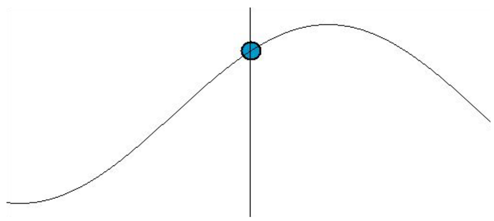

Figure 4. Wave motion (mass up) (Lumen Learning).

Waves can either be longitudinal or transverse contingent on the track of their oscillations. Transverse waves transpire on the basis of a disturbance instigating oscillations perpendicular to the propagation of energy transfer. Oscillations that are parallel to the direction of propagation are known to be longitudinal waves. An electromagnetic wave is normally transverse, while some waves can be both transverse and longitudinal, such as mechanical waves. One longitudinal wave example is sound (Lumen Learning).

Sound travels through liquid and gas as longitudinal waves. However, through solids it can be conveyed as both transverse and longitudinal waves. Longitudinal sound waves (also known as compression waves) are waves of interchanging pressure nonconformities from the equipoise pressure, producing local rarefaction and compression regions. Transverse sound waves in solids are waves of irregular shear-stress perpendicular to the track of propagation (The Physics Classroom).

2.1.3. Generic Sound Properties

Sound waves can be characterized by the following standard properties namely; direction, speed of sound, amplitude and intensity, and frequency (inverse wavelength).

Direction

Sound is omnidirectional (it can travel in any direction). There are various aspects that can influence the direction of sound waves and acoustics. Wind gradient is one example whereby sound propagating along the wind would bend downwards while sound propagating against the wind would bend upwards. Temperature gradients also affect sound waves whereby sound travels faster in a warm atmosphere near the surface of the earth. As the temperature decreases with altitude, there is an upward refraction of sound waves (Softdb, 2019). Figure 5 illustrates the direction of sound.

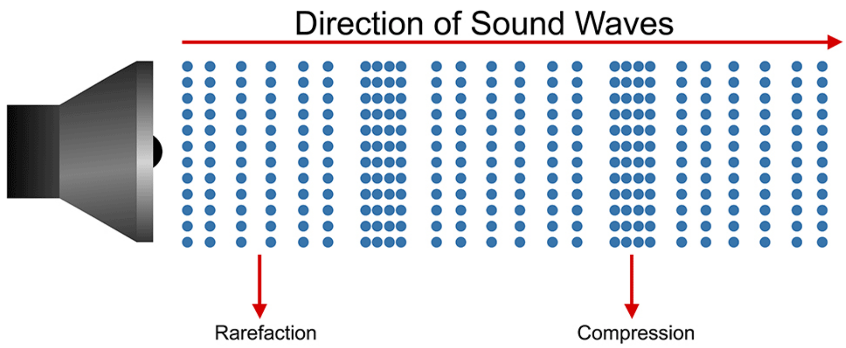

Figure 5. Direction of sound (Sound waves)

In the case of a decrease in temperature with altitude, the refraction would be downwards. Hence variation of temperature gradient causes the sound wave to deviate from its normal path. Finally, atmospheric turbulence, if the atmosphere in which sound is propagating is turbulent, it would lead to scattering of sound waves due to velocity fluctuations of the medium (Nijs and Wapenaar, 1989).

Speed of Sound

An important parameter in the study of compressible flow is the speed of sound (or the sonic speed), defined as the speed at which an infinitesimally small pressure wave travels through a medium, equation 1. The pressure wave may be caused by a small disturbance, which creates a slight rise in local pressure (Cengel and Cimbals, 2018).

$$c = \sqrt{\frac{K_s}{\rho}} \tag{1}$$

Where c is speed of sound, K_s is the coefficient of stiffness, and ρ is density. Sound is influenced by two (2) properties of matter namely; density and elasticity. Therefore, the speed of sound is always different on each scenario. In solids, sound waves travel quicker due to their molecular structure, i.e. tight bonds and closer molecules. Thus, it takes less time for kinetic energy to flow from molecule to molecule. In gases and liquids, the molecules are farther apart and these conditions render sound waves to take longer periods to travel from molecule to molecule (Speed of sound).

Amplitude

In general, amplitude is defined as the maximum magnitude of a sinusoidal oscillation measured from the equilibrium position. It gives the deflection of a physical quantity from its neutral position (zero (0) point) up to a positive or negative value (Chaudhuri, 2010). Figure 6 illustrates a sinusoidal wave defined as a continuous wave.

Considering sound waves, amplitude is the extent to which air particles are displaced, and normally it is experienced as the loudness of sound. Loudness of sound is measured in decibels (abbreviated as dB). The greater the amplitude the greater the sound or noise.

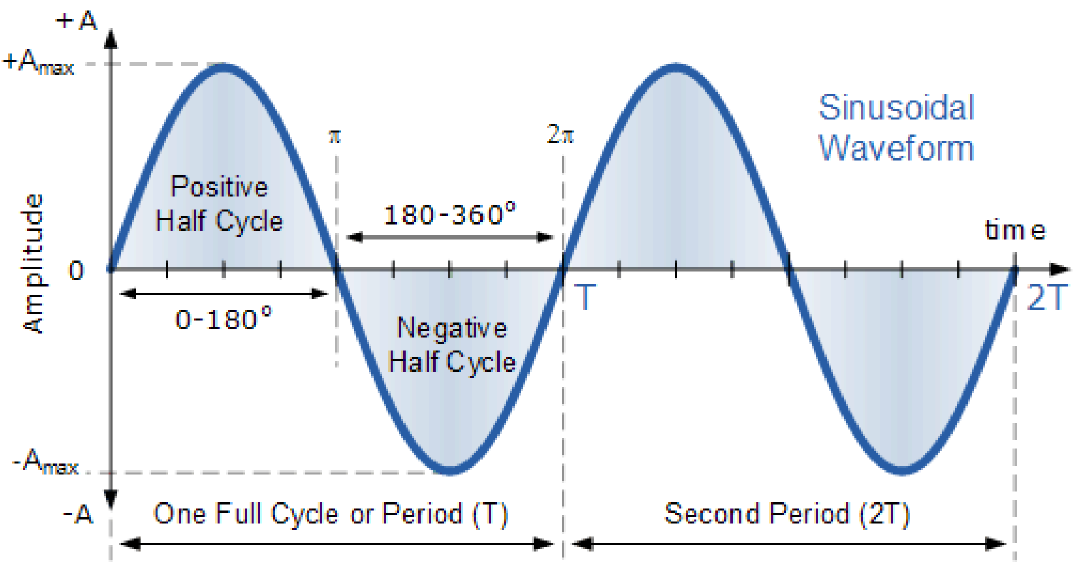

Figure 6. Sinusoidal wave (Man, 2016).

Frequency

Sound is an oscillating wave that has a vast continuum of frequencies. Frequency is defined as the quantity of sequences per second normally measured in Hertz (abbreviated Hz) (Mark, 2001). The principles of frequency are that the higher it is, the smaller the distance between each sequential rarefaction and compression, equation 2. It also determines the pitch, which is a sound property that renders the possibility to perceive sounds as both higher and lower (Sound Physics).

$$f = \frac{1}{T} \tag{2}$$

Where f is frequency and T is period.

2.2. Acoustics Technology: Sonic Cleaning

Acoustic cleaning (also referred to as sonic cleaning) devices are utilized to inhibit ash and particulate material accumulation on various plant equipment such as boiler units, ducts, hoppers, and electrostatic precipitators. This methodology of cleaning adopts the use of sound waves to maintain surface cleanliness without being intrusive as compared to other conventional methods. Figure 7 illustrates one example of an acoustic horn.

Figure 7. Sonic horn AC-75C (Airmatic Inc).

Sound energy generates variations in the inert pressure of a flowing air stream, which consequently instigates any particulate matter suspended in the air stream, and the air stream itself, to oscillate. The consequential outcome has the benefit of loosening and removing ash and particulate matter from surfaces in the path of the air stream, including air preheaters; economizers; ESP electrodes, collection plates, and distribution plates; baghouse filter bags; hopper walls; and fan blades. The comparatively non-directional, highly reflective behavior of sound waves minimizes ash and particulate matter accumulation in "blind spots" where conventional cleaning devices such as rapping systems and soot blowers are often ineffective (Power Engineering, 1999).

Sonic cleaning devices typically operate in one of two acoustic environments: audible and infrasonic. In general, as the frequency decreases, the effective power level increases. Audible acoustic/sonic horns maintain frequencies above about 75 Hz so that the natural harmonic frequency of surrounding plant equipment is not reached, which can potentially lead to equipment damage. Infrasonic devices operate at ultralow frequencies, between about 10 and 35 Hz, creating intense gas-stream turbulence that keeps affected surfaces clean. There are some concerns that infrasonic devices, because of their low frequency range, are more likely to damage surrounding equipment. Flat, unsupported surfaces such as ductwork can be more susceptible to induced vibration. Through proper design and engineering, however, infrasonic cleaning can be very effective (Power Engineering, 1999).

The acoustic horn's ability to eradicate particulate matter accumulation depends on its sound vibration force, which is generally known as the sound pressure level (measured in dB). In order to fluidize particulate matter accumulation, the sound pressure level should be greater than 120 dB. The greater the sound vibration force, the more effective the particulate matter removal is attained. The acoustic horn's operating sound frequency is characteristically between 125 and 250 Hz. Normally, frequencies greater than 250 Hz are more perceptible and are highly probable to irritate nearby plant personnel. However, this does not suggest that lower frequencies are preferable. In actual fact, sound pressure levels at frequencies below 60 Hz lose their capability of removing particulate material, while also having the potential of damaging solid structures, such as feeders, silo walls, mechanical connections, dischargers, and support legs (Smith, 2008).

As explained, acoustic energy requires to be monitored and regulated in order to warrant the production of low frequencies are not reached since they pose an undesirable consequence of damaging nearby surrounding objects. This possible structural integrity compromise is a result of vibration of kinetic energy (sound waves) that induce vibration on nearby surrounding objects.

3. Conclusion

The term acoustics in itself has a broad meaning whereby it is applicable in various fields such as music, architectural spaces, and ultrasound medical imaging just to name a few. It has been demonstrated that sound is a form of energy that creates atmospheric pressure fluctuations generated by turbulent fluid flow and vibrating surfaces. A device that utilizes this phenomenon is an acoustic horn, that generates sound energy to inhibit ash and particulate material accumulation on various equipment such as hoppers, ducts, and boiler units. One of the benefits of using acoustic energy is that none intrusive cleaning of the plant's internal substructure apparatus can be attained. The nature of sound propagation induces vibration on surrounding objects, such that if not monitored and controlled, the device may have detrimental effects on plant equipment (Mhlongo and Kallon, 2021).

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Biographies

Mr. T. Mafokwane attained a Bachelor of Technology in Mechanical Engineering at the University of Johannesburg (UJ) in 2017. He had earlier graduated with a National Diploma in Mechanical Engineering from the University of Johannesburg (UJ) in 2016. He has also been a tutor at the Mechanical and Industrial Engineering Technology department at the University of Johannesburg for the Computer-Aided Drawing module in 2013, and a Mechanical Engineering Drawing module in 2016 and 2017. Autodesk Revit Architecture certified user award conferred at Modena Design Centres in 2017. His primary research area entails vibration and strain sensor modelling and control systems engineering design.

Dr. Daramy Vandi Von Kallon is a Sierra Leonean holder of a PhD degree obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT. At the start of 2014 Dr Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer. In May 2014 he transferred to the University of Johannesburg as a full-time Lecturer and later a Senior Lecturer in the Department of Mechanical and Industrial Engineering Technology (DMIET). Dr Kallon has more than twelve (12) years of experience in research and six (6) years of teaching at University level, with industry-based collaborations. He is widely published, has supervised students from Master to Postdoctoral levels and has graduated seven (7) Masters Candidates. His primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration Analysis, Water Research and Engineering Education.