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NONLINEAR GAS DYNAMIC WAVES: SOME REAL WORLD APPLICATIONS

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Abstract

The theory of nonlinear gas dynamic waves or shock waves plays a vital role in the understanding the most of mathematical, biological, and engineering sciences. The solutions of governing non linear partial differential equations (PDEs) of shock waves are used to study the flow field of various nonlinear phenomena, for example, supersonic flows, explosions, earthquakes, piston motion, surface of a star, etc. While considerable progress has been made in the shock wave research on traditional applications like aerospace engineering, the research in multi disciplinary applications such as agriculture, industry and medical sciences is relatively new and still needs to be done. This paper highlights some interdisciplinary applications of shock wave technology in medical, industry and agricultural areas.

***Key words**: Shock waves, nonlinear PDEs, biomedical applications, shock wave therapy.*

Introduction: Nonlinearity plays a vital role in the understanding the most of physical, chemical, biological, and engineering sciences. Since the last few years, the research in nonlinear gas dynamic waves or shock waves has progressed rapidly due to its wide range of practical applications in various branches of science and engineering. The nonlinear gas dynamic wave is a type of disturbance of large amplitude, propagating at supersonic velocity, across which, the flow parameters such as pressure, density, temperature etc. change intermittently [1]. For example, in steady transonic or supersonic flows, during explosions, earthquakes, lightning strokes, flow field in a piston motion, surface of a star, flows of gas fuel within a jet engine, etc. The invention of supersonic aircraft and atomic bomb during the Second World War demanded better theoretical understanding of shock phenomena. Some of the important traditional applications include designing aerospace vehicles flying at supersonic speeds, the blast wave signature which provides the strength of the explosions, detecting the shock waves generated during earthquakes etc.

The mathematical theory of nonlinear conservation laws can describe shock waves by using nonlinear partial differential equations (PDEs). The simplest form of hyperbolic equation describing shock wave phenomena is $u_t + [f(u)]_x = 0$, considered as the basic model for the nonlinear wave propagation. The mathematical and numerical study of solutions to these nonlinear PDEs helps in understanding the existence and behaviour of wave propagation under different material media and hence can be used for various real life applications. For example, shock wave propagation in Extracorporeal Shock Wave Therapy (ESWT), a technology in medical field, can be investigated computationally by solving the isentropic Euler equations in the fluid and linear elasticity in the bone using high-resolution finite volume methods [2]. The research of shock wave assisted applications in the areas of agriculture, industry and biological sciences is relatively new and still needs to be explored. In this paper, I highlight some of the medical, industrial and agricultural applications of shock wave technology.

Medical Applications: Shock waves have been successfully used in the field of medicine for more than three decades for various treatments and therapies with the first medical application patented in early 1940s. It was during the Second World War that the effect of shock waves, created by the exploding bombs on tissue cells was first observed. There has been a rapid progress in the development of shock wave therapy in the last few years. Shock wave assisted new technologies like Extracorporeal Shock Wave Therapy (ESWT), Extracorporeal Shock Wave Lithotripsy (ESWL), etc are changing how various ailments are treated. Today, shock wave therapy is considered to be one of the advanced, feasible, effective non-invasive treatments.

Extracorporeal Shock Wave Lithotripsy (ESWL): Disintegration of kidney stones by shock waves which utilizes high-energy acoustic waves to break up urinary tract stones seems to be a promising form of shock wave treatment. Till the early 1980s, the most common technique for treatment of urinary stone disease was by open surgery which involved multiple surgeries, complicated procedures and long recovery time period. ESWL, the most effective treatment for non-invasive removal of urinary tract stones, has revolutionized the treatment of kidney stone disease. This therapy, an alternative to the traditional surgical removal of kidney stones, was introduced in the early 1980s. Today, ESWL is the first choice for the treatments related to kidney and urethral stones. ESWL uses approximately one-two thousand, high-intensity shock waves to crush the kidney stones into tiny pieces or fragments that are small enough to pass in urine.

ESWL may not be suitable for stone size more than 2 cm diameter and effective for smaller size. The method does not work always and can cause kidney damage. ESWL can rupture blood vessels leading to severe renal injury. Research findings report post therapy risks and complications involved in ESWL [3]. Some of them are internal bleeding, common infections and kidney failure. Apart from post therapy complications, there are some limitations and serious adverse effects of using ESWL as some types of kidney stones are highly resistant to shock waves. However, technological advances such as slow shock wave rate and step-wise treatment are being used to improve the success rate and reduce renal injury. Radiologic techniques also play a significant role in various issues like, appropriateness of ESWL treatment, evaluation of treatment complications and hence success of the therapy. The factors like size, number, location and composition of the kidney stones are considered for applying this treatment. Improved lithotripter techniques like the use of multiple focus machines, better coupling designs and better localization real-time monitoring may enhance the quality of the treatment in the future[4].

Extracorporeal Shock Wave Therapy (ESWT): ESWT is a method of noninvasive therapeutic treatment for soft tissue injuries, which is still considered as an emerging non-invasive therapy method. It works by passing shock waves into the tissues. ESWT helps in healing the wounds and controlling pain. ESWT can be used in various treatments like tumour treatment, where laser assisted shock waves are used for mechanical destruction of cancer cells which helps to eliminate cancer cells to prevent further growth, gene manipulation where it is used to treat various hereditary diseases which cannot be cured by traditional medical therapy, for destruction of white blood cells while treating for leukaemia and HIV diseases, in sports medicine for its soft tissue healing and regenerative effect by reducing the recovery time after injuries.etc.

Extracorporeal Shockwave technology for Myocardial Revascularization (ESMR): One of the optimal medical applications of shock waves is in the field of cardiovascular medicine and for Ischemic Heart Disease. The ESMR therapy is a new approach to non-invasive therapy using Extracorporeal Shockwave technology for improving the blood and oxygen supply to heart muscles. As conventional revascularization therapies like bypass surgery has difficulty in accessing Ischemic myocardial areas, ESMR therapy can be used as an alternative treatment. The

ESMR technology produces low intensity shockwaves via a special generator, supported against the patient's chest by a water cushion. These are targeted at the ischemic myocardial tissue in order to stimulate the growth of new blood vessels which helps the supply of blood and oxygen to the heart muscles[5]. Now the ESMR is a safe, cost -effective treatment and has no adverse side effects.

It has been reported in several research works that, the mechanical compression and/or shear stress caused by the propagating shock wave is thought to stimulate healing [3]. This extends the applications to orthopedics and traumatology to treat insertion tendinitis, a vascular necrosis of the head of femur and other necrotic bone alterations. Another field of shock wave application is in veterinary medicine for the treatment of tendons, ligaments and bones on horses. Shock waves have been considered for applications such as treatment of soft-tissue pain, promoting repair or growth of bone, neo-vascularisation and wound healing. Shock waves are also used to destroy biological contaminants and harmful microorganisms and hence to clean and sterilize different fluids.

Agricultural and Industrial Applications: Some of the shock wave assisted applications in biological sciences, industry and agriculture that have been developed in the recent past are, preservative injections to wood slats, oil extraction, metal forming, food processing and preservatives, design of musical instruments and reduction of bio-burden in natural products, needleless vaccine delivery system, pencil industry etc [6]. We consider some of them.

Wood Preservatives: It has been reported in the research that, when fungi and other micro organisms like bacteria in suspension are exposed to repeated application of micro-shock waves, there is an exponential decrease in the population of micro organisms and hence they can be destroyed. This will help in improving the bio-resistance and enhancing the life of wood samples like tropical hard woods and bamboo samples as there are technical difficulties to treat these types of woods. A lot of research and practical experiments are in progress to explore the possibility of micro-shock wave-assisted clearing of vessel blockages in timber to ensure the infiltration of water-soluble preservatives for better wood preservation and reconditioning of secondary timber. Also, shock wave-assisted preservative delivery systems are under development for better and efficient infiltration of preservatives into woods like catamarans which are used in the fabrication of fisherman boats.

Extraction of Sandalwood oil: Sandalwood oil, one of the expensive oils has been used in medicine as an antiseptic, in the manufacture of perfumes and cosmetics. A common and traditional method employed for extraction of sandalwood oil has been steam distillation method. It has been experimentally proved that the rate of oil extraction and quantity of oil when wood samples are exposed to shock waves are higher than compared to traditional steam distillation method. Scientific investigations conclude that the squeezing of the interior oil globules in the sandalwood sample due to shock wave loading is the important cause for the enhancement of sandalwood oil extraction.

Pencil Industry: Pencils are made of soft woods which are used to cover the graphite rods in them. In the initial processing stage, water soluble preservatives are impregnated into the wood samples to enhance the life of pencils. The traditional method called power processing, generally takes more time for processing of wood samples. In [6], a new system called shock waves assisted preservative impregnation technique and the role it plays in reducing the manufacture processing time were discussed briefly.

Food preservatives: Due to constant increasing customer demand for high quality natural, nutritious and fresh food, various non-thermal technologies for food processing and preservation have been explored for the past few years. Traditional and widely used method to inactivate harmful microorganisms and enzymes in food processing and preservation is thermal treatment. But the disadvantage of this treatment is the nutritional loss, physical and chemical changes. One of the emerging non-thermal alternative technologies in food processing is by using shock waves. The use and efficiency of shock wave assisted food preservative technique still needs to be evaluated for the commercial purpose. Other shock wave-assisted applications in food industry which need further exploration are, dry preservatives to protect agricultural products like pulses from pests, preservatives to increase the tenderness of meat by breaking the fibres(commonly known as hydrodyne process), and many others. Research also reports experimentally proven fact that shock waves can act as abiotic stress in modifying growth of crop plant seedling.

Musical Instruments: Weak shock waves emanating from brass musical instruments were observed by Hirschberg et al. The nonlinear propagation of shock within brass instruments plays a significant role in giving ``brassy'' characteristic of musical instrument under loud playing conditions. It was noticed that musical instruments like trombones or trumpets which have a segment of cylindrical pipe near the mouthpiece of the instrument, played at loud volume would produce shock waves [7]. When played with pressurized air, wind instruments such as whistles and sirens can produce shock waves (sounds with large amplitudes). Shock waves in a straight shock tube are very well understood, and are well modelled by one-dimensional gas dynamics. Research about the understanding of propagation of shock waves in curved tubes is not yet been done. The study of shock waves in curved tubes in musical instruments helps in understanding the relationship between the curved shape of the instrument and the sound it produces. The tubes behave differently regarding the focusing effect, depending upon curved cylindrical tubes, curved rectangular or two-dimensional tubes.

Concluding remarks: In the past few decades shock waves have been successfully applied to medical, biological and industrial applications. However, the biological mechanism and effects of shock wave therapy are not completely understood and the complexity of shockwave administration has been underestimated. The efficiency of shock wave assisted technological applications is not always clear and the mechanisms are poorly understood. A better understanding of mathematics and physics of shockwaves can help to reduce complications like adverse technological effects. Key research fields such as medical applications of shock wave to various therapies are to be further explored. I conclude here that, the multidisciplinary research, pilot and case study should be done to explore the wide range of shock wave applications which may be the beginning of fascinating era in medicine, agriculture and industry.

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