Introduction to Explosions and Safety - Video course

COURSE OUTLINE

Starting with the definition of the word explosion, the conditions for which disruption of things at the site of the explosion would occur and examples of the different categories of explosions are discussed. The mechanism of formation of shocks and blast waves are investigated and predictions for a blast wave using the Buckingham Pi theorem are given.
The equation for a shock Hugoniot is derived from the conservation equations and the jump in pressure, temperature, density across a constant velocity shock wave is calculated. The impulse and overpressure across a blast wave is thereafter modeled and the scaling laws arrived at for determining overpressure and impulses. Explosion length is introduced as an appropriate scaling parameter. Since the energy release rates must be fast enough to drive an explosion, methods of predicting energy release and energy release rates are dealt with. Induction time is defined and a long induction time or equivalently a high value of activation energy is seen to be essential for an explosion to occur.
The theory of thermal explosion is derived in the context of heat release rates and heat loss rates. Flames and detonations are thereafter discussed following a discussion of one dimensional combustion waves. Limits of flammability and limits of detonation, limiting oxygen concentration and fire point and flash point temperatures of volatile liquids are examined in the context of fire and explosion safety.
Confined and unconfined gaseous explosions, dust explosions and condensed phase explosions are thereafter considered. Different condensed phase explosives and their chemical structure are discussed. Physical explosions and cryogenic explosions and the TNT equivalence of the non-ideal explosions are discussed. Since atmosphere plays a major role in dispersing gaseous substances and mixing them with air to form an explosive, the role of atmospheric dispersion is also discussed. The course concludes with quantification of damages, some basics of risk analysis, acceptable risks and use of Fault Tree and Event Tree analysis for predicting the probability of an explosion.

COURSE DETAIL

Lecture 1	INTRODUCTION: What constitutes an Explosion, Sound Waves, Derivation for Sound Velocity, Steepening of Sound Waves from Impulsive Energy Release, Shock Waves, Loud Noise and Disruption.
Lecture 2	BLAST WAVES AND EXPLOSIONS: Blast waves and Loud Bang, Isentropic Wave Motion and Non-isentropic Shocks, Examples of Explosions occurring in Nature - Lightning, Volcanic Eruptions, Meteors, Comets and Asteroids, Stellar.
Lecture 3	TYPICAL EXPLOSIONS: Accidental Explosions – Condensed Phase Thermal Explosions, Confined and Unconfined Explosions, Boiling Liquid Expanding Vapor Explosions (BLEVE), Dust Explosions, Physical Explosions, Hazard and Risk.
Lecture 4	TYPICAL EXPLOSIONS AND CLASSIFICATION: Intentional Explosions – Nuclear Explosions, Artillery and Armaments, Improvised Explosive Devices (IED), Constructive uses of Explosions, Implosions, Atmospheric Dispersion- Great Smog of

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Mechanical Engineering

Pre-requisites:

- Basic course in Thermodynamics,
- First level course in Fluid Mechanics

Additional Reading:

1. Crowl, D. A., and Louvar, J. F., Chemical Safety: Fundamentals with Applications, Prentice Hall, 2002
2. Stull, D. R., Fundamentals of Fire and Explosions, AIChE Monograph Series, vol. 73, No. 10, 1977
3. Strehlow, R. A., and Baker, W. E., Characterization and Evaluation of Accidental Explosions, NASA CR 134779, 1965
4. Boddurtha, F. T., Industrial Explosion Prevention and Protection, McGraw-Hill, New York, 1980

	London, Bhopal Gas Tragedy, Classification of Explosions.
Lecture 5	BLAST WAVE MODELING: Prediction of Blast Wave Strength from Explosions using Buckingham Pi Theorem, Formulation and Analysis, Ideal and Non-ideal Explosions and Blast Waves.
Lecture 6	BLAST WAVES (Contd.): Summary of Predictions for Blast Wave using Dimensional Analysis, Taylor's Prediction for Nuclear Explosions, Non-Dimensional Decay coefficient for a Blast Wave
Lecture 7	SHOCK WAVES AND BLAST WAVES: Introduction, Mass, Momentum and Energy conservation Equations across a Shock, Shock Hugoniot, Rayleigh Line.
Lecture 8	PREDICTIONS FOR SHOCK WAVES: Rankine-Hugoniot Relations, Equations of State, Derivation of Jump in Density and Pressure across a Shock of a given Mach Number, Velocity Prediction behind Shocks in Frame of Reference of Shock and an Inertial Frame of Reference
Lecture 9	PREDICTIONS FOR BLAST WAVE: Summary of Pressure, Density, Velocity and Temperature behind Constant Velocity Shocks, Extrapolation of Shock Predictions for Blast Wave, Estimation of pressure, and temperatures in Shocks formed when Meteor entered Atmosphere over Siberian Plains.
Lecture 10	BLAST WAVE CHARACTERISTICS: Analysis for Concentration of Mass at Blast Wave Front (Snow plow model, Validity of Snow Plow Approximation for Strong Blast Waves, Mechanism of Damage Produced by Blast Wave. Examples with Numerical Predictions
Lecture 11	BLAST WAVE PREDICTIONS (Contd.): Overpressure and Impulse from Blast Waves, Explosion Length as a Scaling Parameter, Sach's Scaling, Overpressure from an Ideal Explosion as a Function of Scaled Distance.
Lecture 12	IMPULSE AND OVERPRESSURE: Side View of Variation of Pressure behind Blast Wave, Impulse from a Blast Wave, Non-dimensional Impulse, Predictions of Non-Dimensional Overpressure and Non-dimensional Impulse for Strong and Weak Blast Waves.
Lecture 13	SUMMARY OF PREDICTIONS FOR BLAST WAVES: Cranz-Hopkinson's Scaling Laws for Overpressure and Impulse, Missiles and Fragments, Tutorials on Solving Problems in Blast Waves.
Lecture 14	ENERGY RELEASE: Modeling of Impulsive Energy Release in an Explosion, Moles and Mass, Standard Heats of Formation, Calculation of Energy Release using a Simple Model for Stoichiometric, oxidizer-rich and fuel rich Explosives.

5. Arya, S. P., Air Pollution Meteorology and Dispersion, Oxford University Press, New York, 1999
6. Cooper, P. W. and Kurowski, S. R., Introduction to the Technology of Explosives, Wiley VCH, 1996

Coordinators:

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Lecture 14	ENERGY RELEASE (Contd.): Solving Problems of Energy Release in Fuel-rich and Oxidizer rich Explosives, General Trends.	
Lecture 15	RATE OF ENERGY RELEASE: Energy Release Rates in a Chemical Reaction, Concentration, Law of Mass Action, Arrhenius Law, Variations of Reaction Rate, Temperature and Concentration in a Chemical Reaction with Time, Role of Activation Energy.	
Lecture 16	THERMAL EXPLOSIONS: Calculation of Heat Release Rates in Typical Chemical Explosions, Dependence on Concentration, Volume and Energy Release Per Unit Mass in a Lumped Mass System, Loss Rates through Heat Transfer, Thermal Theory of Explosions.	
Lecture 17	THERMAL EXPLOSIONS (Contd.): Preheat, auto-ignition and Ignition Energy in the Context of Thermal Theory, Characteristic Heat Loss and Characteristic Heat Release Times, Damkohler Number, Solving Problem of Thermal Explosion in the Worst Industrial Disaster at Texas City.	
Lecture 18	REQUIREMENTS FOR AN EXPLOSION: Role of Induction and Reaction Times in an Explosion, Importance of High Activation Energy, Characteristic Times, Conditions for an Explosion to Occur.	
Lecture 19	FLAMES: Relaxation of Lumped Mass Assumption in Thermal Theory, Ignition, Flame Travel, Burning Velocity and Flame Speed, Estimation of Burning Velocity, Thickness of Flame.	
Lecture 20	FLAMES (Contd.): Laminar and Turbulent Burning Velocities, Quenching Thickness, Peclet number, Davy's Safety Lamp, Maximum Experimental Safety Gap, Flame Kernel, Estimation of Ignition Energies.	
Lecture 21	FLAMMABILITY LIMITS: Introduction, Upper and Lower Limits, Estimation and Mechanism, Upward and Downward Flame Propagation and Limits, Minimum Oxygen Concentration and Maximum Safe Oxygen Concentration (MSOC), Solving for MSOC.	
Lecture 22	FLAMMABILITY LIMITS (Contd.): Calculations involving limits, Explosions involving Volatile Liquids, Flash Point Temperature and Fire Point Temperature. Saturation Temperature, Fog, SMOG, Analysis of Explosion of Boeing 747 in TWA 800 Flight.	
Lecture 23	COMBUSTION WAVES: Introduction, Reaction Hugoniot, Realizable States on the Reaction Hugoniot, Rayleigh Line, Chapman Jouguet Points	
Lecture 24	DETONATIONS AND DEFLAGRATIONS: Introduction, One Dimensional Theory, Chapman Jouguet Detonation, Zeldovich-von Neuman-Doring Idealized Model of a Detonation, von Neuman Pressure Spike, Pressure, Density and Temperature behind a Detonation.	

Lecture 25	DETONATION: Three Dimensional Mutiheaded Structure of a Detonation, Detonation Cell Size, Modeling of the Initiation of a Detonation, Detonation Kernel like a Flame Kernel, Deflagration to Detonation Transition, Blockages in Flow, Quasi-detonations.
Lecture 26	FLAMES AND DETONATION: Solving Problems Regarding Flames and Detonations for Propane- Air Explosion at Port Hudson, Missouri and World's Largest Man Made Explosion at Ural Mountains, Siberia.
Lecture 27	GASEOUS EXPLOSIONS: Unconfined, Confined and Partially Confined Gas Explosions, Maximum Pressure and Severity, Role of Blockages, Explosions in Tunnels and Safety, Review of Problems related to Explosion at Falk Corporation at Wisconsin and in Downtown Stockholm.
Lecture 28	DUST EXPLOSIONS: Introduction, Minimum Explosive Concentration and Dust Particle Size, Estimation of Concentration in Gravity Feed and Forced Feed, Detonation, Smoldering and Secondary Explosions.
Lecture 29	DUST EXPLOSIONS (Contd.): Solving Problems in Dust Explosions, Severity, Sensitivity, Minimum Ignition Energy and Index of Explosibility of Dust Mixtures, St Classification, Non-volatile Dusts.
Lecture 30	PHYSICAL EXPLOSIONS: Introduction, Use of Liquid - Vapor Phase Equilibrium for Flash Vaporization, Estimation of Energy Release, Solving Problems.
Lecture 31	CRYOGENIC EXPLOSIONS AND EXPLOSIONS IN PRESSURE VESSELS: Rollover in Cryogenic Fluid Storage and Physical Explosions, LNG Containers, Explosions in Pressure Vessels, Solving Problems of Pressure Vessel Explosions.
Lecture 32	CONDENSED PHASE EXPLOSIVES: Introduction, Chemistry of Explosives, Explosives based on Saturated Chains Comprising Straight Chain and Ring Compounds, Alkadienes and Aromatic Compounds, Detonation in Explosives.
Lecture 33	EXPLOSIVES: Condensed Phase Explosives based on Fulminates, Azides, Acetalide, and Stephnates, Characteristics of condensed Phase Explosives, Enhancement of Energetics, Plastic Explosives, Low, Primary and Secondary Explosives.
Lecture 34	TNT EQUIVALENCE AND YIELD: Introduction, Energy and Blast Equivalence, Yield, Problem Solving.
Lecture 35	ATMOSPHERIC DISPERSION: Introduction, Temperature Inversion, Pasquill Classification of Atmosphere, Dispersion of a Parcel in the Atmosphere, Atmospheric Stability.

Lecture 36	ATMOSPHERIC DISPERSION (Contd.): Diffusion Equation and Gaussian Solution, Standard Deviation Coefficients, Dispersion in Three Dimensions, Puff and Plume, Dispersion Coefficients, Dispersion of Buoyant and Heavy Gases.
Lecture 37	ATMOSPHERIC DISPERSION (Contd.): Solving Problems on Dispersion with Specific Reference to Dispersion of Vapor from a Ruptured Pipeline and for the Bhopal Gas Tragedy.
Lecture 38	DAMAGES FROM EXPLOSIONS: Quantification of Damages to Life and Property, Cumulative Distribution, Dose, Probit and Standard Deviation, Linear Response using Probit, Probit Parameters.
Lecture 39	RISK ANALYSIS: Introduction, ALARP, Fault Tree and Event Tree Analysis, Gates, Hazop, Other Methods, Problem Solving.
Lecture 40	SAFETY ASPECTS: Explosion and Fire Safety, Vents and Burst Doors, Maximum Safe Experimental Gap and Critical Size, Ignition Energy, Fire and Explosion Triangle, Accidental Energy Sources.

References:

1. Kinney, G. F. and Graham, K. J., Explosive Shocks in Air, Springer, Berlin, 1985
2. Baker, W. E., Explosions in Air, University of Texas Press, Austin, 1973
3. Ramamurthi, K., Explosions and Explosion Safety, Tata McGraw Hill, Delhi, 2011