ABSTRACT

Dry Ice is Carbon Dioxide (CO_2) in solid form. Cold ice particles (approx -78^{0}C) can be blasted on the surfaces to be cleaned with compressed air. This leads to thermal tension in the deposits, causing cracks and embitterment, in turn breaking off the contaminants. This technique is very gentle and environment friendly. No harmful blasting agents/ residues such as waste water or granules are left behind, as solid CO_2 goes backs into the air in gaseous state after strike.

The same technique has been applied first time to clean the bore of the gun barrel. With many others, the main contaminant left in the bore is copper. For which a lot of effort and resources are required to clean. The copper is easily removed by dry ice blasting.

In current research paper, a complete study on the application of dry ice, its comparison with other blasting techniques and its environmental effects are carried out. A practical / demonstration of gun bore cleaning with dry ice blasting were carried out in HIT with the cooperation of a private firm PAIE. After the demonstration, on the bases of results obtained, certain recommendations were given. The CFD analyses of the given recommendations were carried out. Moreover the effect of dry ice blasting on parent material were also studied in detail and then proved practically and numerically.

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CHAPTER-1

INTRODUCTION & LITERATURE REVIEW

1.1 Background:-

It is the name given to CO_2 in solid form. It is in the earth's atmosphere, humans and plants use it. It is a colorless, odorless, tasteless, and about 1.5 times heavy than air. Carbon dioxide turns from gas to solid under pressure and at low temperatures, at −109° F(-78.5°C).It is produced generally in two forms, one as a block of dry ice of 50 lb (22.7 kg), two in small pieces that vary in size of a grain of rice to a larger pellet. It does not melt, instead it sublimates, that is, the solid turns directly into a gas as the temperature increases.

It itself is not poisonous, but in cold form its surface can not be touched without gloves. Also, while the gas is stable and inert, it is heavier than air and can concentrate in lower areas or closed places. When the concentration in air exceeds 5%, the carbon dioxide becomes toxic. Thus, the area in which dry ice is used be well ventilated. [1]

It is simple to turn CO_2 from a gas to a solid. Many dry ice manufacturers shipped it for a variety of uses. It is an important refrigerant to keep foods cold and preventing bacterial growth during long preservation**.** Dry ice used for cooling or freezing foods is considered to be a “food grade” to ensure that food it touches should not be wasted. Since the solid sublimates**,** large quantities of dry ice can be put into shipping containers without considering volume of melting water that accumulates when ice is used as a refrigerant. Food-related uses include quick freezing of foods for future use at food processing plants and keeping foods chilled.

Other uses include: slowing the growth of flower buds at nurseries to keep always plants fresh, flash freezing in the rubber industry during manufacture, absorbing ammonia refrigeration leaks, and creating smoke for theatrical productions. The most important recent application of dry ice is dry ice blasting in which dry ice pellets is blasted at a surface to be cleaned. The pellets strike the surface of the contaminants, sublimate into the atmosphere, and leave no toxic gases or byproduct. The only residual is the dirt or paint left behind to dispose. [1]

1.2 History:-

It was not invented, but discovered in the early twentieth century. It was first produced commercially in the 1920s in the U S A. commercially trademarked as *dry ice* in 1925 and being said as dry ice since then. Recently, it is often called as *hot ice,* due to the fact that when touched the surface the hand felt as burned.

Prest-Air Devices Company of Long Island, USA first successfully produced it in 1925. Also in same year, Schrafft's of New York City first used it to avoid its ice cream to melt. It was extensively used for refrigeration and freezing of foods in twentieth century than it is being used today. Almost every ice cream parlor in the world used dry ice for keeping ice cream frozen until World War II, when electric refrigeration was not available. The manufacturing of dry ice has not changed significantly for many decades and is a relatively simple process of pressurizing and cooling gas CO_2. Uses of dry ice gave better results than electric refrigeration. Some recent developments for its use include using the blasting or cleaning and its increasing use in transporting medical specimens, including hearts, limbs, and tissues, for reattachment and transplantation of various organs.[1]

In 1945 U S Navy used dry ice as a blast media for many degreasing applications. In May 1963, Reginald Lindall, a U S scientist used a “method of removing meat from bone” using “jetted” carbon dioxide particles. In November 1972, Edwin Rice, a U S scientist used a method for the removal of unwanted portions of an article by spraying with high-velocity dry ice particles". Similarly, in August 1977, Calvin Fong used "Sandblasting with pellets of material capable of sublimation".[2]

The work and success of these early Inventers led to the formation of many companies in the early 1980's to the development of dry ice blasting technology. In 1986, Cold Jet®, Inc. was founded in USA.

Dry ice palletizes and dry ice blasting machines entered the industry in the late 1980's. At that time the blasting machines were very large, very expensive, and they required very high air pressure (greater than 200 psi). As the CO_2 / dry ice blasting technology advanced, the dry ice blasting machines' size and cost dropped, and today, the latest nozzle technology has made blasting at air pressures of 80 psi .[2]

1.3 What is Dry Ice Blasting ?

It is a new cleaning process using solid CO_2 pellets. It converts directly from a solid blast pellet to a vapor with no residue. It has got popularity due to its environmental and many production benefits. Because of environmental benefits and reduced costs, it has been discovered that it is the best process to minimize wastes also. Such benefits are force multiplier due to performance gains through dry ice blasting with no production downtime, quality of clean equipment and no damage. It is the solid form of CO_2, which is a colorless, tasteless, odorless gas found in our atmosphere.

At -109°F (-78°C), solid CO_2 has an inherent thermal energy ready to be tapped. At atmospheric pressure, it converts directly to vapor without going through a liquid phase. This property means that the blast media simply disappears, leaving only the contaminants. In addition, blast cleaning in water sensitive areas is now practicable by this method of cleaning. [2]

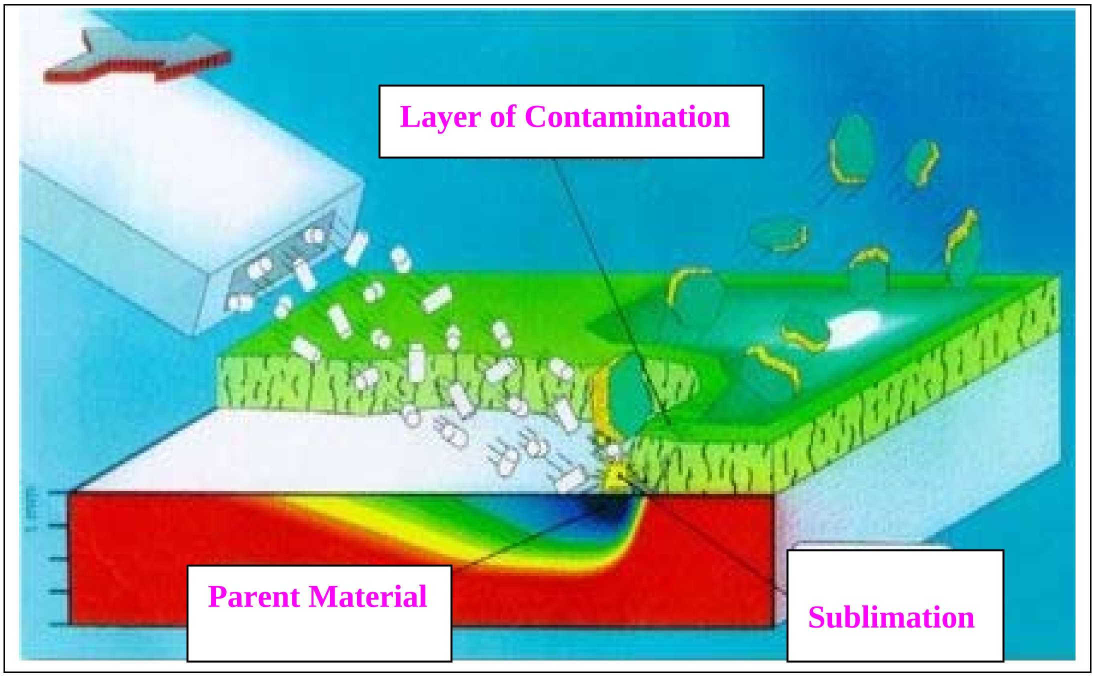


Figure-1.1:- Dry Ice Process [4]

CO_2 is a natural life sustaining media. It is an important element in the carbon cycle. It is the only source of carbon for agriculture. It helps plant growth and to moderate the temperature of the earth. "Animal respiration is assumed to add 28 million tons of carbon dioxide per day into the atmosphere. By contrast, the U S CO_2 industry can supply only 25,000 tons per day and 95% of this is from by-product sources, and less than 0.04% of the other sources combined". [2]

CO_2 used in dry ice blasting is the same as used in the food and beverage industry. It is a non-poisonous, liquefied gas that is inexpensive and easily stored. It is non-conductive and non-flammable. [2]

It is a natural by-product of several industrial manufacturing processes such as petrol-chemical refining industries. The CO_2 produced by the above production processes is caught and stored. When the CO_2 is returned to the atmosphere during the blasting process, no new CO_2 is produced. Rather, the original CO_2 by-product is released. [2]

It is non-conductive, inert, non-poisonous and nonflammable. Its advantages are its ability to clean sensitive surfaces and no residues of the blasting medium after the blasting process since it turns from solid to gas at room temperature. [3]

Dry ice blasting is also known as:[3]

a. Dry Ice Cleaning

b. Dry Ice Blast Cleaning

c. CO_2 Blasting

d. CO_2 Blast Cleaning

e. Cryogenic Blast Cleaning

f. Cold Jetting

1.4 Raw Material:-

The raw material used in dry ice is only CO_2. It is the byproduct of gases emitted during the manufacture or other products. Carbon Dioxide used in the manufacture of dry ice in U S is derived from refinement of gases given off during the refinement of petroleum and ammonia. The carbon dioxide emitted during these processes is sucked off and eventually become dry ice. [1]

Figure-1.2:- The Dry Ice [5]

1.5 Use In Blast Cleaning:-

Dry ice pellets are fired from a nozzle with compressed air. This removes residues from parent material. Examples of materials being removed include ink, glue, oil, paint, mold and rubber. It can replace sandblasting, steam blasting, and water blasting / solvent blasting or any other kind of blasting. The primary environmental effect of dry ice blasting is CO_2. As the source of dry ice is typically pre-existing CO_2, the net environmental impact is zero with no damage done, no gain or loss. [2]

1.6 The Basic Processes:-

CO_2 blasting works with three primary factors:-

- Pellet Kinetic Energy
- Thermal Shock Effect
- Thermal-Kinetic Effect

1.6.1 Pellet Kinetic Energy:- [3]

It is a nonabrasive kinetic impact force which is a product of the dry ice pellet mass and velocity over time. It achieves the greatest impact force of a solid CO_2 pellet by throwing the pellets at supersonic speeds.

At very high impact velocities and direct head-on impact, the kinetic effect of CO_2 pellets is lesser as compared to other medias like grit, sand etc. It is due to the softness of solid CO_2, which is not as dense and hard as other medias can be. Also, the pellet changes from a solid to a gas immediately upon impact, a very little impact energy is transferred to the substrate, during the process.

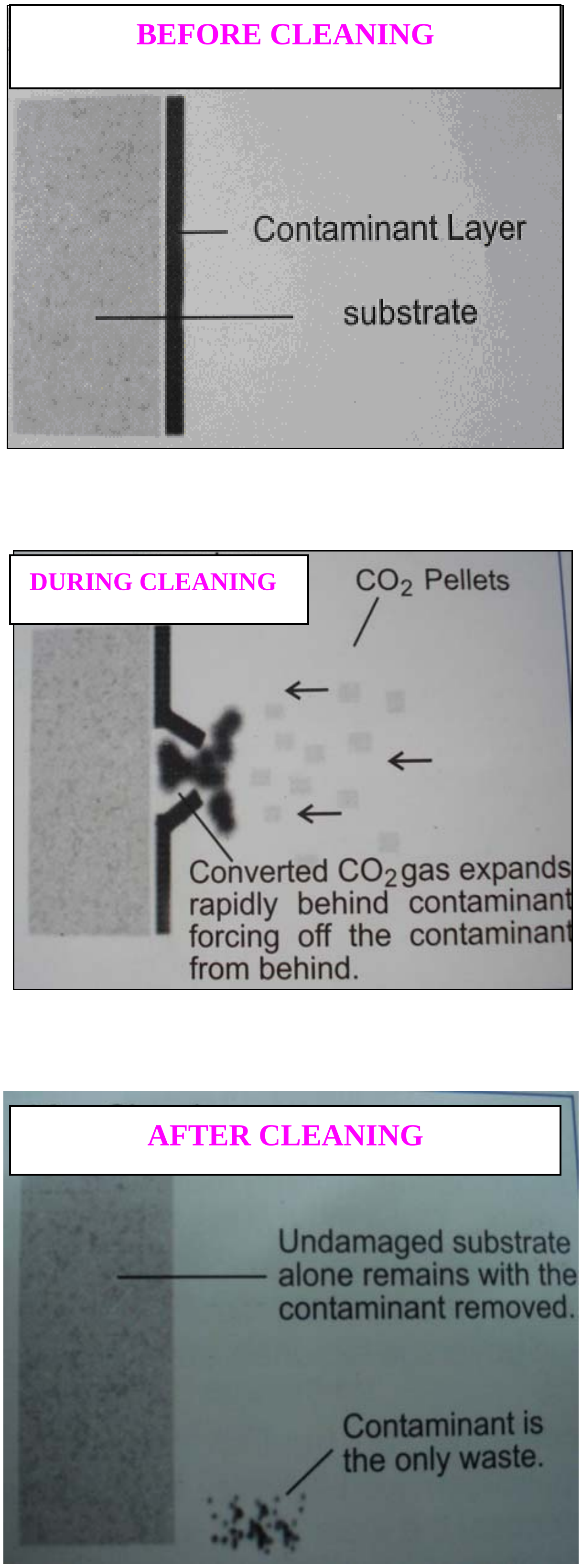


Figure-1.3:- The Process Illustration [5]

1.6.2 Thermal Shock Effect:-[3]

Immediate phase change from solid to gas of CO_2 pellet after impact absorbs maximum heat from the top layer of surface coating or contaminant. Maximum heat is absorbed due to latent heat of sublimation. The very rapid transfer of heat into the pellet from the coating top layer creates an extremely large temperature differential between adjacent micro-layers within the coating. This sharp thermal gradient produces high shear stresses between the micro-layers of coating. These shear stresses are also dependent upon the coating thermal conductivity and thermal coefficient of expansion/contraction, as well as the thermal mass of the underlying substrate. The high shear produced for very little time results rapid micro-crack propagation between the layers leading the contaminant (or coating) final bond failure at the surface of the substrate or parent material.

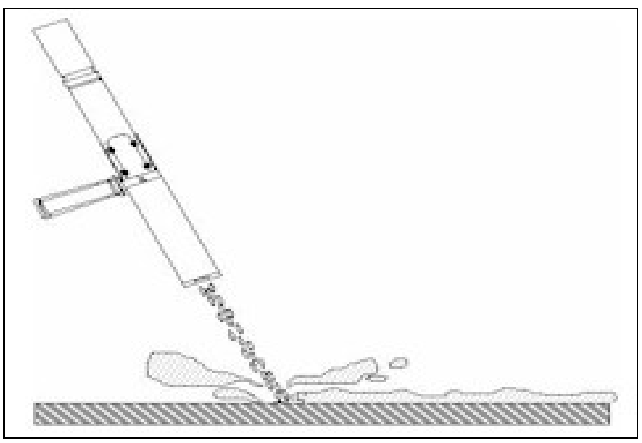


Figure- 1.4:- Thermal Shock Induces Micro-Cracking in the Surface Coating [2]

1.6.3 Thermal-Kinetic Effect:- [3]

The combined impact energy dissipation and extremely rapid heat transfer between the pellet and the surface cause instantaneous sublimation of the solid CO_2 into gas. The gas expands to nearly 800 times the volume of the pellet in a few milliseconds in what is effectively a "Micro-explosion" at the point of impact.

The "Micro-explosion," as the pellet changes to gas, is further enhanced for lifting thermally-fractured coating particles from the substrate. This is due to the pellet's lack of rebound energy, which tends to distribute its mass along the surface during the impact. The CO_2 gas expands outward along the surface and its resulting "explosion shock front" effectively provides an area of high pressure focused between the surface and the thermally fractured coating particles. This results in a very efficient lifting force to carry the particles away from the surface.[3]

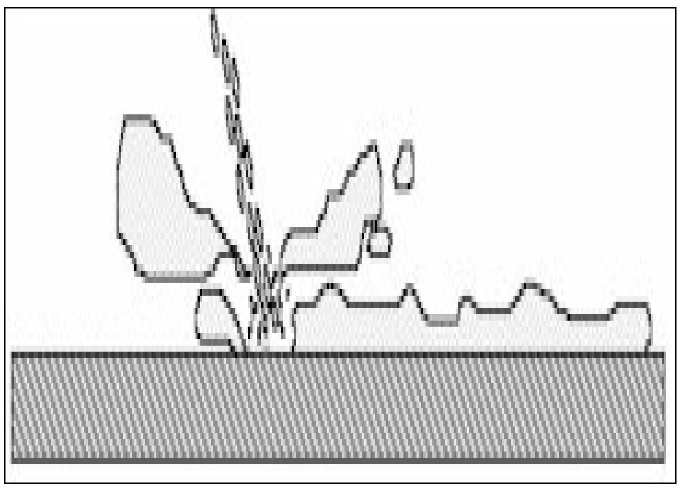


Figure-1.5:- CO_2 Gas Expansion and Pellet Kinetic Effects Break Away and Remove Coating Particles [2]

1.7 Dry Ice Products:-

It is generally available in the following forms:-

a. Blocks

b. Nuggets

c. Pellets [5]

Figure-1.6:- Blocks [4]

Figure-1.7:- Nuggets [5]

Figure-1.8:- Pellets [6]

1.8 Places Using Dry Ice [7]:-

1.8.1 Electrical:-

a. Electronic /Electrical Control Panels

b. Cable trays Motors/Stators

c. Armatures/Coils/Windings

d. Generators

e. Printed Circuit Boards

f. Semi-Conductors

g. Transformers

h. Switch Gear

i. Robotic Equipment

j. Relays

k. Turbines

l. Insulators

1.8.2 Food:-

a. Ovens

b. Floors

c. Walls

d. Processing Equipment

e. Equipment Ceilings

f. Conveyors

g. Bake Trays

1.8.3 Commercial:-

a. Buildings

b. Exterior/Interior

c. Hospitals Nursing Homes

d. Hotels

e. Residential

f. Structures

g. Heating/Cooling Systems

h. Bricks Wood

i. Remediation/Restoration

1.8. 4 Industrial

a. Molding Equipment

b. Butt Welders

c. Process Equipment

d. Manufacturing Equipment

e. Piping

f. Tanks

g. Ship Hulls

h. Automobiles Interiors

i. Printing Presses

j. Pulp/Paper Equipment

k. Oil Field Equipment

l. Boiler Tube

m. Aircraft

1.8.5 Other:-

a. Cigarette/Cigar Smoke

b. Formaldehyde

c. Beauty Salons

d. Waste Containers Nuclear Decontamination

1.9 Benefits of CO_2 / Dry Ice Blasting:-

1.9.1 Decreased Downtime through Cleaning In-Place:-

Dry ice blasting lesson the downtime for cleaning from days down to hours. General cleaning techniques require that equipment be disassembled and then moved to a special area for proper cleaning. Dry ice blasting needs no such requirement. Equipment is cleaned at-place and generally in hot situations. Due to this, many time-consuming and labor-intensive steps are eliminated including: [8]

a. Cool down time

b. Disassembly

c. Transportation of the equipment to and from a specified cleaning area

d. Reassembly

e. Reheating time

1.9.2 Faster and More Thorough Cleaning:-

Using CO_2 cleaning, a better clean can be gained with reduced work as when compared with other abrasive material or wire brush. A great savings in labor is achieved. Also, the CO_2 blast can cleans in deep and narrow places that cannot be achieved by hand. Due to this, equipment works more efficiently and future leaks are saved thus preventing major system failures. [8]

1.9.3 Elimination of Equipment Damage:-

CO_2 blasting often finishes the chances of equipment damage. The methods like sandblasting have an aggressive and abrasive effect on the surface of material. It removes some part of the parent surface, and changes the surface structure. Since CO_2 is non-abrasive, so it does not change any surface structure. It throws the contaminants away. In addition, now the equipment is cleaned at the place, the damage of moving equipment to and from a specified cleaning area is eliminated. [8]

1.9.4 Reduction or Elimination of Solvents:-

CO_2 blasting is without solvents, and uses harmless CO_2 pellets. This supports the need for some user to comply with environmental regulations and worker place safety. There is no problem of toxicity. [8]

1.9.5 Reductions in Waste Disposal:-

With other cleaning methods, whether it is with solvents, sand blasting or some other media, the cleaner itself becomes contaminant and require to be disposed off along with the primary contaminant. However, with CO_2 blast cleaning since the CO_2 pellet vaporizes on contact, the only waste is the contaminant itself. This leads to significant waste reduction.

1.9.6 Increased Safety:-

CO_2 blasting pellets are non-toxic, non-hazardous so supporting to the environment, employees, work place and production facility and includes: [8]

a. No secondary waste

b. Safe for the environment

c. Safe for employees

d. Safe for end products

e. Safe for equipment

f. Safe for work place

1.10 Conclusion:-

The use of dry ice in refrigeration and food storage may be less important, but its use in other areas has much importance. As discussed, house cleaners and machinery owners are requiring small dry ice pellets to bombard a house or machine at high pressure, to remove dirt or other contaminants, and dissipate CO_2 into the atmosphere. Recently a communication company used dry ice to clean sensitive electronic testing equipment without using dangerous solvents as they already use. Car body repair have discovered that applying dry ice to dents in the body can sometimes eliminate the disfiguration. Also, tests on dry ice blocks advocate dropping it into gopher holes to eradicate the pests or putting it out in the backyard to attract mosquitoes in order to keep them away from humans.

Dry Ice Blasting reduces or eliminates the need for toxic solvents. This results in less human exposure to dangerous solvents and reduces managerial liability. Solvent reductions are a result of using this CO_2 process and are necessary to comply with state regulations. This process gives better worker safety. When removing hazardous material with other blasting media such as sand, glass beads, walnut shells, water, etc., both contaminant and blast material must be disposed of as toxic waste. Because dry ice (CO_2) sublimates after strike, so no additional waste is generated.

All this proves that its future is very bright. There are certain applications, like electrical circuits, its application are seem to be necessary.

CHAPTER-2

GUN BORE CLEANING

2.1 Introduction:-

In the previous chapters, the detailed discussion of dry ice blasting has been made. The process allows almost all the surfaces cleaned, which require cleaning. It can remove the weaker contaminants as oil, fats or hard as rust, paints etc. It a non-abrasive with no by-product / contaminate after the blasting, also requiring no disassembly of the equipment to be cleaned is required.

It is very interesting that no significant military application has been noted in past. Its naval application is in the depainting of the boats / ships. In air force the cleaning of turbine blades is done through this process. However, in military there is no such application in use. Its military application may include de-painting of vehicles/equipment, removal of rust from old placed equipment and the most important is the bore cleaning of a gun.

In this chapter, the barrel cleaning of 125 mm gun barrel with dry ice will be discussed, as it is being rebuilt in HIT. Before go into the detail the basics of a gun are discussed.

2.2 What is Gun? [14]

The gun has two main components.

2.2.1 The Ordnance:-

This is the part of the gun in which the explosive force is used to give direction, momentum and stability to a projectile. It includes:-

a. Barrel

b. Jacket

c. Muzzle brake

d. Fume Extractor

e. Breech Mechanism

f. Firing Mechanism

g. Means of Obturation

2.2.2. The Carriage or Mounting*:* - [14]

This is the part of the gun that supports the ordnance. It consists of a basic structure and a super structure as:-

2.2.2.1 The Basic Structure: - [14]

a. Saddle support

b. Trails

c. Articulation System

d. Spade/Platform and Tie Bars

2.2.2.2 The Super Structure: - [14]

a. Saddle.

b. Elevating, Traversing and Balancing Gear.

c. Elevating mass.

d. Sighting System.

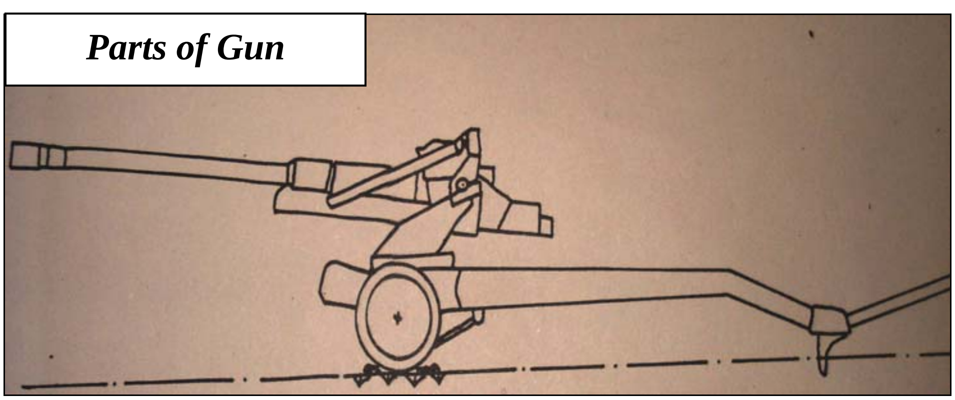


Figure- 2.1: - Parts of Gun [14]

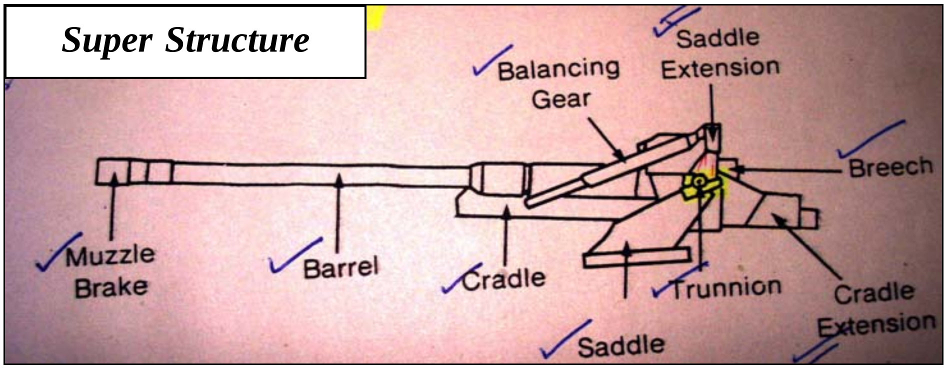


Figure- 2.2: - Super Structure [14]

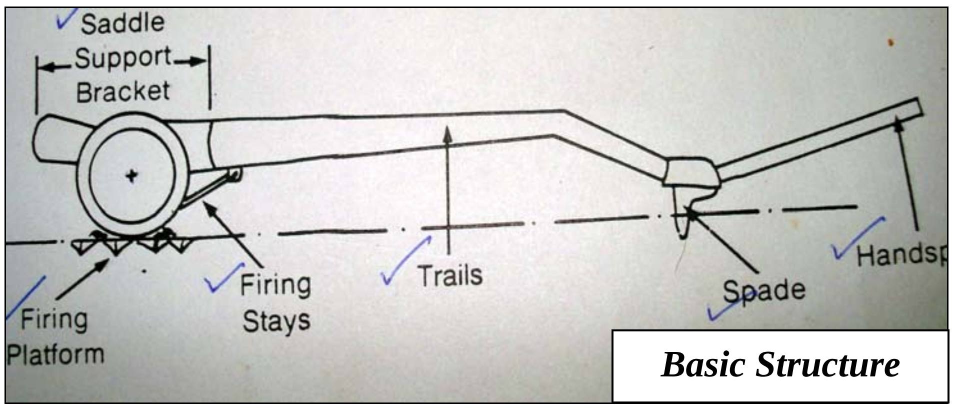


Figure- 2.3:- Basic Structure [14]

2.3 What is Barrel?

This is a tube of high grade steel along which the projectile passes on firing. The tube is usually rifled to spin the projectile, thereby stabilizing it in flight. Smooth bore barrel are also in use. [14]

2.3.1 Firing Stresses in Barrel:-

The walls of the barrel must be sufficiently strong to withstand the effects of gas pressure. A study of the pressure- space curve shows that the barrel must have its greatest strength at the breech end where the pressure is highest. As the pressure falls off towards the muzzle, the thickness of the barrel may be reduced. The stresses are: - [14]

a. Radial Stress

b. Hoop Tension Stress

c. Longitudinal Stress

d. Girder Stress

e. Torsion Stress

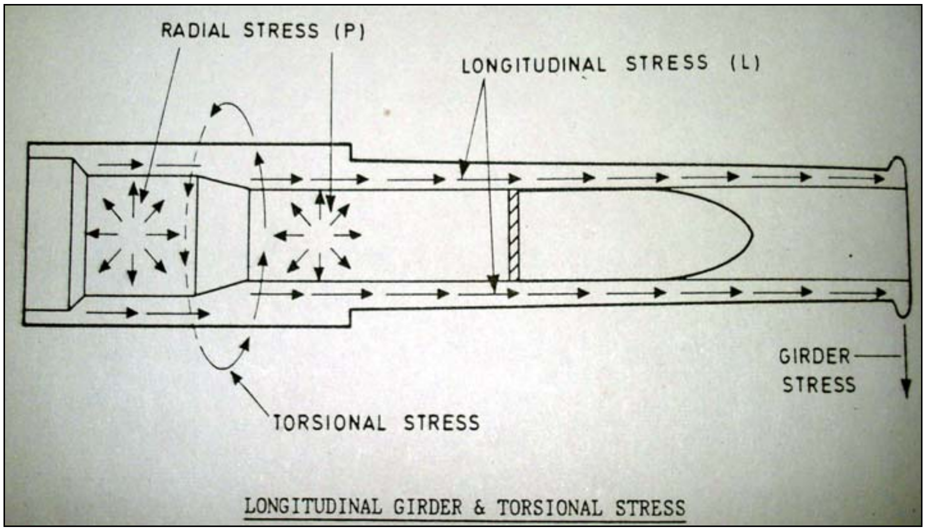


Figure- 2.4:- Stresses in Barrel [14]

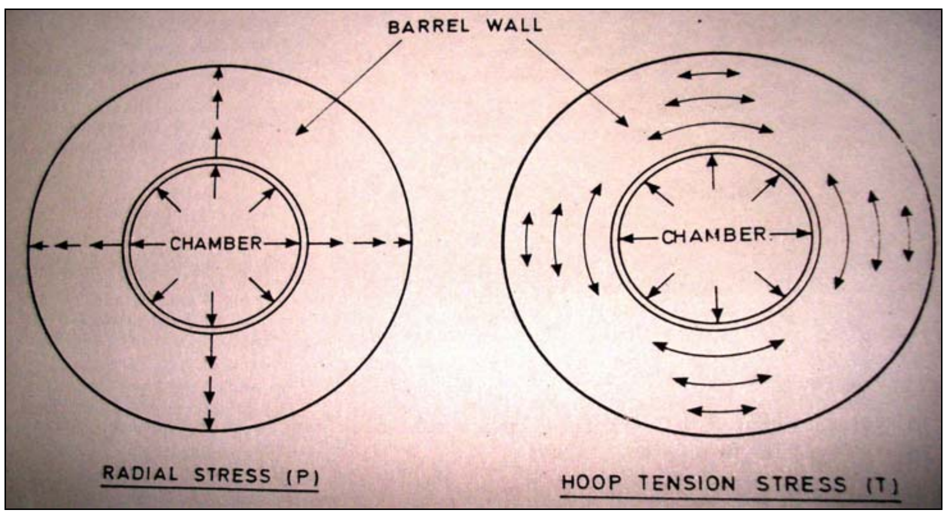


Figure- 2.5:- Stresses In Barrel [14]

2.3.2 Strength of the Barrel:-

The nature of these stresses, which act together in three dimensions, is illustrated in figure. The thickness of the barrel walls must be designed to make the barrel strong to withstand all the stresses and depends on the grade of steel used. [14]

2.3.3 Ordnance Weight*: -*

The foregoing consideration indicates that overall weight of a barrel depends directly on the stresses involved. This is related to the angle of the gun, its weight of shell and caliber as well as the value of the maximum gas pressure. As the range of equipment increases, the stresses increase and consequently an increase in ordnance weight and /or strength is required. [39]

2.3.4 Design Consideration of Barrel: - [14]

The barrel is designed to

a. Direct the flight of shell.

b. Give shall rapid spin for steady flight.

c. Give required muzzle velocity

2.3.5 Rifling and Driving Band*:-*

Rifling is the system of helical grooves and lands formed by the cutting of grooves in the bore. The primary functions of the driving band/rifling combination are as follows: - [9]

a. To rotate the projectile.

b. To provide a gas seal round the projectile.

In addition the driving band**:-**

a. In guns using separate ammunition to prevent slip-back of the loaded projectile when the gun is elevated by engaging the shot seating.

b. Assists in centering the projectile in bore.

c. Prevents movement of the projectile until the gas pressure has risen to shot start pressure.

2.4 Estimated Remaining Life of a Barrel:-

2.4.1 General:-

The early method of estimating the serviceability of a gun tube by the number of rounds fired was entirely unsatisfactory when variables such as varying weights and types of projectiles, varying rates of the fire, varying number of rounds fired in a group, etc., were introduced . The actual life of an individual gun tube in records might vary from 10 per cent to 300 per cent of the average life figure. [10]

2.4.2 Equivalent Full Charges (EFC):-

As an approximate rough guide for estimating the difference in round life, the term “equivalent full charge” (EFC) was adopted. One round of the primary ammunition for the pertinent cannon has been designated as one EFC round with a factor of 1.00. Other ammunition used is designated specific EFC round to the estimated remaining life in rounds of that particular ammunition. These factors are provided primarily to assist personnel engaged in planning tube requirements.

Tube condemnation will always be based on actual bore measurement and visual inspection: under no condition will a tube be condemned based on actual or EFC rounds fired. [10]

2.4.3 Tables: -

An estimated life in EFC rounds has been established for each tube for estimating remaining life only. Tables have been prepared to show the estimated remaining life in percentage and in EFC, rounds for a given pullover gauge reading. The remaining life in rounds of a particular type of ammunition can be computed using the applicable EFC factor given in the pertinent table. For example if the pullover gauge reading of a tube in a 120-mm gun cannon M58 is 4.880 inches, a reading of the table for this weapon will show an estimated remaining life of 150 in EFC rounds. If it is desired to show this life in rounds, using the HEAT Projectile M356 (T15E3) the figure 150 will be divided by EFC factor 0.094 giving an estimated quantity of 1596 rounds. [10]

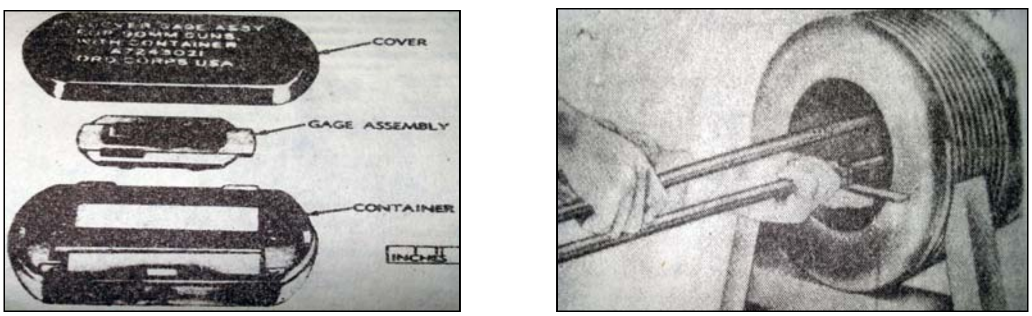
$$150 / 0.094 = 1596$$

2.5 Inspection of the Bore of Barrel:-

Various types of gages & instrument are used for the purpose of locating evaluating and inspection of the extent of erosion and damage in the bore. These instruments make it possible to identify the type and degree of erosion or damage and there by offer a mean of evaluating and estimating the life of barrel and ballistic accuracy. [11]

2.5.1 Pullover Gauge*: -*

The pullover gage is used to measure the wear of bore diameter of all kind of artillery weapon. It is a rugged accurate gage used in the field. The gage employs a venire type slide that is calibrated in thousands of an inch from the standard size of the bore being measured. [3]



. **Figure- 2.6: - Pullover Gauge [11]**

2.5.2 Bore scope: -

The bore scope is used to visually inspect the bore of all type of arty weapon for defects and damages caused by the fire. It is basically a straight tube using a mirror or prison set at an angle to present a view of the bore being inspected. [11]

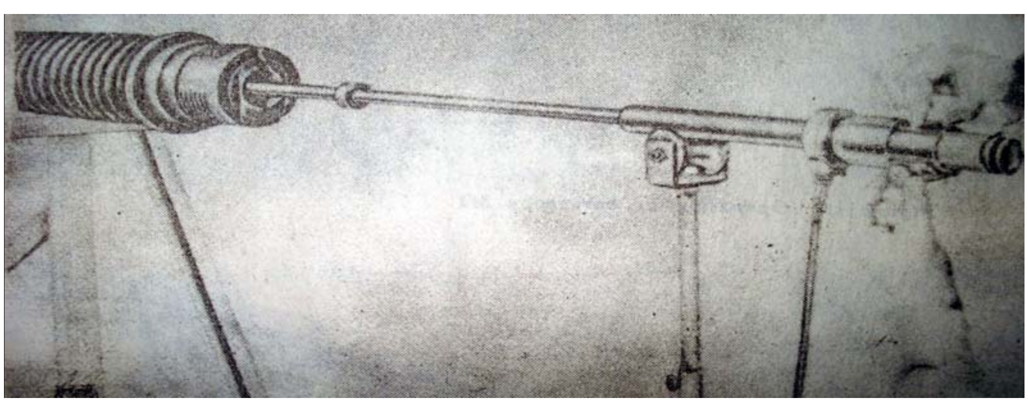


Figure-2.7: - **Bore Scope [11]**

2.5.3 Pressure gage: -

The pressure gage consists of a steel cap, a copper gas check cup, and steel hosing that contains a steel piston and a copper cylinder. The steel cup closes the housing at one end and the gas check cup close the other end.. When the power charge ignites, the pressure of the expanding gases is exerted against the check cup. It is transmitted to the steel piston to move and compress copper cylinder against the steel cup. The compression of the cylinder, difference in height before and after the fire, is measured with a micrometer. [11]

2.6 Remnants Left in the Barrel after Fire:-

Following are the remnants left in the bore after fire: - [14]

•	Carbon	Due to the burnt gasses and smoke left as the projectile leave.
•	Rust	Normal phenomena
•	Copper Band	It is caused by sticking of copper from the rotating band of shall. It is with HE & HEAT rounds.
•	Nylon Band	It is caused by sticking of nylon from the rotating bends of APFSDS rounds.
•	Dirt & Dust	Natural dirt /dust after fire. Old Lubricants - Used for long preservation

2.7 Methods of Barrel Cleaning:-

2.7.1 In the Field:-

The purpose of bore cleaning is to remove the old lubricant, dirt, carbon deposits and for decoppering and nylon band removing. [9]

2.7.1.1 Copper Deposits: - [24]

2.7.1.1.1 Cause: -

Copper deposit is a layer of copper alloy deposited from the projectile driving band on the rifled portion of the bore.

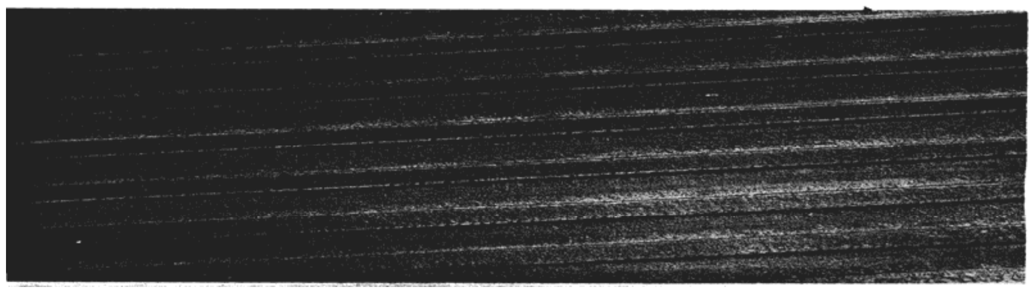


Figure-2.8:- Bore of 155 mm from Breech Face Showing Light Coppering [24]

2.7.1.1.2 Appearance: -

In the early stages, the surface of the rifling lies a copper tint.

2.7.1.1.3 Remedy: -

In order to reduce coppering in British ordnance to a minimum a de-coppering agent of tin or lead foil is included in all serving charges except for the smaller natures of howitzer. The quantity inserted in charges of a new design of ordnance and adjusted in new supplies of ammunition as a result of experience, to give the best results. Special de-coppering rounds containing double the normal gravity of the or lead foil were provided in the past for certain QF natures. These are now obsolete. The chemical method of de-coppering is to be used on when necessary to investigate bore defect, including steel choke. It consists of plugging the bore at breech and muzzle and filling with a suitable solution to remove the copper by chemical action. For this a PYC solution is prepared, the PYC solution is consisting of:-

a. Water - 1 Liter

b. Chromic an hydraulic - 300 Grams

c. Aluminum sulfate - 100 Grams

2.7.1.2 Lubrication:-

Gun grease 54 is used for long term storage of bore and lubrication.

2.7.1.3 Rust/Dirt/Dust:-

K-2 oil is used.

2.7.1.4 Fine Cleaning Of Bore-

Linen cloth is used**.**

2.7.1.5 Carbon:-

Linen cloth with swab cleaning rod is used.

2.7.1.6 Cleaning procedure: - [12]

a. The purpose of barrel cleaning is to remove the old lubricant, dirt and carbon deposits. To facilitate the cleaning of bore directly after fire, while the barrel is till hot, coat the bore with grease .It will soften the carbon deposits.

b. Using a trowel apply a thick coat of lubricant to a cleaning rod, swab and introduce the cleaning in to the bore ,the barrel position be horizontal, after Roding 2-3 hours proceeds to washing the bore with kerosene oil or soapy water.

c. Soapy water should be applied to the bore not less than three times. Remove the soap with the help of cleaning road washed in clean water.

2.7.1.7 Advantages:-

a. An old process

b. A familiar process

c. Easy operation

d. Can be started at any time

e. Start immediately after fire

2.7.1.8 Disadvantages:-

a. Delay in cleaning may give settle time for copper/ carbon deposits

b. Long cleaning time required

c. Since the manual movement of cleaning rod is not uniforms it may cause damage to bore

d. No proper way to measure the extent of cleaning.

e. Strong build persons are required

f. Maximum crew effort is required.

g. Separate decoppering process.

2.7.2. Bore Cleaning System: - [13]

A bore cleaning system commercially named airmes bore cleaning system can clean barrels up to 155 mm. Its advantages are-

a. Removal of firing deposits

b. Removal of inhibiting oil

c. Applicant of oil to clean barrel.

d. It can work from 25 mm barrel to upward

It is based on a cylindrical, air power tool and the range of ferrets. A selection of brushes, tailored to a specific size, is fitted to the front of the ferret, which houses an oscillating piston. When the brush end is entered into the barrel and air supply is switched on, the energy generated by the oscillating piston will drive the ferret and brush in the direction of least resistance This is not very popular in the field as of its limited supply and high cost. This system is also designed to works in the field.

2.7.3. Bore Cleaning Machine*:* - [15]

This machine is made by the students of EME College. It is still in prototype form. This machine is made with following service requirements;

a. It should be designed as per field requirement.

b. Power source should be easily available in the field.

c. Require minimum crew effort

d. It should remove the carbon deposits after fire.

e. Should not require any platform for operation.

f. Should be lightweight and portable

g. Should not damage the bore in case of malfunction of machine.

h. It will work will 125 mm smooth bore gun.

2.7.3.1 Major components:-

It is consists of following parts;

a. Drive motor - 24 V DC

b. Worm and gear ratio - 1:22

c. Tire and supporting roller.

2.7.3.2 Drive machine:-

It is able to enter in to barrel with cleaning element and power source. High torque is required at he tires to give a smooth drive in the barrel. Drive shaft has to drives four tires of assembly.

2.7.3.3 Cleaning Mechanism:-

Installed brush gets drive from motor at the front of the assembly. It consists of layers of stuffed fabric cloth which remove the carbon from the bore immediately after fire.

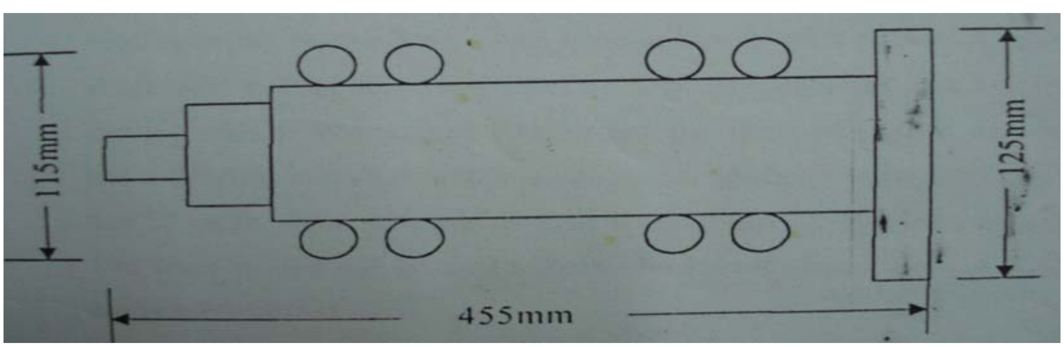


Figure- 2.9: – Description of Cleaning Machine [15]

2.7.4 Bore Cleaning at HIT:-

The new barrels are cleaned in HIT. Since there barrels are brand new and without fire so there is no firing residues in the bore to clean. It is just the bore polishing with 100% exact dimension of the bore. Some proof fired barrels with 4-5 fires are also cleaned in the same manner.

It consists of a long fixture. The barrel is tied on that fixture at one and on the other end of the fixture, there is a long rod. The length of the rod is equal to the length of the barrel. At one end of the rod a swab equal to the bore of the barrel is tied. The swab is covered with fine emery sheet and fine stuffed fabric cloth. The other end of the rod is fixed with a machine that moves the rod along with the swab in to the bore throughout the length of the barrel. This swab move sometimes with emery sheet and sometimes with fabric cloth. Movement of rod is made several times till the final finish of the bore.

Figure- 2.10: – Bore Cleaning at HIT

CHAPTER-3

COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

3.1 Introduction:-

CFD is a tool which shows complete behavior of flow in any domain**.** Here CFD analysis is required for gun cleaning with dry ice before doing the practical. Since it does not require any material / practical expenditure but produces the same results. In the succeeding paragraphs, the CFD analysis is discussed in detail with reference to our problem**.**

Here CFD analysis is used to calculate the effect of forces generated by the jet of CO_2 & air on the face of pig & the wall of the bore. Our main concern is to calculate the maximum stress created by jet of CO_2 & air at different velocities. From here we will conform that these stresses are compatible to the allowable stresses of the gun bore material & intelligent pig material. For our CFD analysis we assume that CO_2 is in gas form with greater density.

3.2 Software Used:-

Following Software is used for our CFD analysis:-

a.	Grid Generation -	Gridgen 15.10
b.	Processing-	Fluent 6.10
c.	Post Processing-	Field View 10.0

3.3 Grid Generation:-

Gird generation is the primary requirement for CFD analysis. A 3 D structured grid was made for the analysis.The Grid was made by using Gridgen 15.10 in which clustering was done near intelligent pig and the stream of air and CO_2. The grid has the following specification: -

No of Cells = 129930

No of Blocks = 4

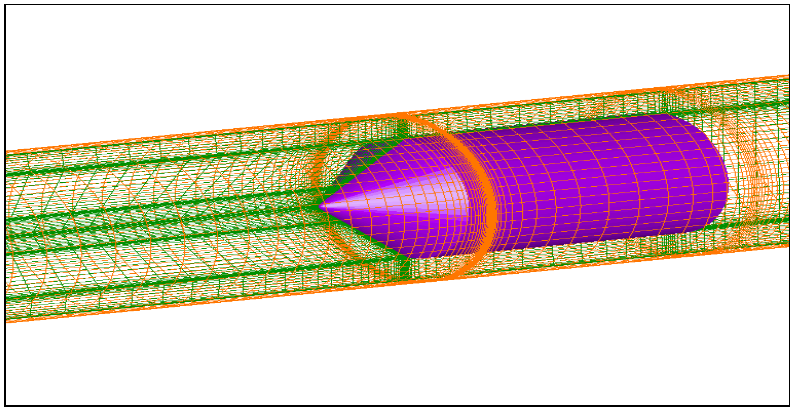


Figure- 3.1:-The Grid Generation

3.4 Governing Equations:- [20]

Reynolds Average Navier Stokes (RANS) equation was used with Spalart Allmaras (SA) turbulent model for the subject analysis. Reynolds Average Navier Stokes (RANS) equations and the transport equation for SA Model can be written as:-

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right] + \frac{\partial}{\partial x_j}(-\rho\overline{u_i' u_j'}) \qquad (2)$$

$$\frac{\partial}{\partial t}(\rho\tilde{\nu}) + \frac{\partial}{\partial x_i}(\rho\tilde{\nu}u_i) = G_\nu + \frac{1}{\sigma_{\tilde{\nu}}}\left[\frac{\partial}{\partial x_j}\left\{(\mu + \rho\tilde{\nu})\frac{\partial \tilde{\nu}}{\partial x_j}\right\} + C_{b2}\rho\left(\frac{\partial \tilde{\nu}}{\partial x_j}\right)^2\right] - Y_\nu + S_{\tilde{\nu}} \qquad (3)$$

Where

Gv is the production of turbulent viscosity.

Yv is the destruction of turbulent viscosity.

Sv is the user defines source term.

3.5 Solver Parameters & Boundary Conditions:-

The parameters used in CFD analysis were the same upon which actual practical will be performed. Boundary conditions and the domain are shown in the figure below. Field view 10 was used for post processing in the analysis. The conditions are:-

a. Diameter of the air and CO_2 Jet = 1 inch.

b. Velocity of the air and CO_2 Jet = 90 m/sec

c. Surface of the bore = no slip wall

d. Surface of the pig = no slip wall

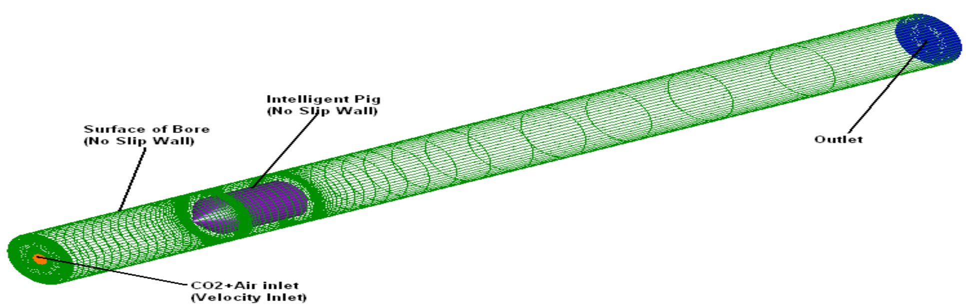


Figure- 3.2:-The Boundary Conditions

3.6 Results:-

With our suggested option along with the parameters discussed in our previous paragraphs, the CFD analyses were carried out which showed the complete behavior of the flow as under:-

3.6.1 Stress Calculations:-

3.6.1.1 Intelligent Pig:-

Material	Cu Alloy
Yield Stress	760MPa

Case-1:- **At velocity = 90 m/s**

Stress =Force / Area

Area = 3.14x $(.110)^2$ /4 = 9.489x10^{-3}

Force = 13224 N

Stress = 1.393 MPa

The stress on the pig has far less value than yield stress of pig material.

Case-2:- **At velocity = 180 m/s**

Stress (σ) = Force / Area

Area = 3.14x $(.110)^2$ /4 = 9.489x10^{-3}

Force = 15972 N

Stress = 1.7 MPa

The stress on the pig has far less value than yield stress of pig material in this case also.

3.6.1.2 Bore of Barrel:-

Material	discussed earlier
Yield Stress	900 MPa

Case-1:- **At Pressure = 2.85 bar**

Stress σ (hoop) = (pressure x diameter) / 2t

Pressure= 2.85 bar

Diameter= 0.125 m

Thickness= .0127 m

Stress σ (hoop) = 1.4 MPa

The stress on the bore has far less value than yield stress of bore material

Case-2:- **At Pressure = 3.5 bar**

Stress σ (hoop) = (pressure x diameter) / 2t

Pressure= 3.5 bar

Diameter= 0.125 m

Thickness= .0127 m

Stress σ (hoop) = 1.7 MPa

The stress on the bore has far less value than yield stress of bore material in ths case also.

3.6.2 Pressure Contours:-

The pressure contours showed that the maximum pressure was exerted on the nose of the pig and after striking the nose again the maximum pressure was found on the surface of the bore. Hence the maximum pressure of air and CO_2 jet was achieved on the surface of bore. Figure below shows pressure contours on the surface of the bore in XY plane. Maximum pressure was found on the nose of the pig and on the surface of the bore. It also indicates the low pressure at the edges of pig cone, due to the obvious reason of separation of flow

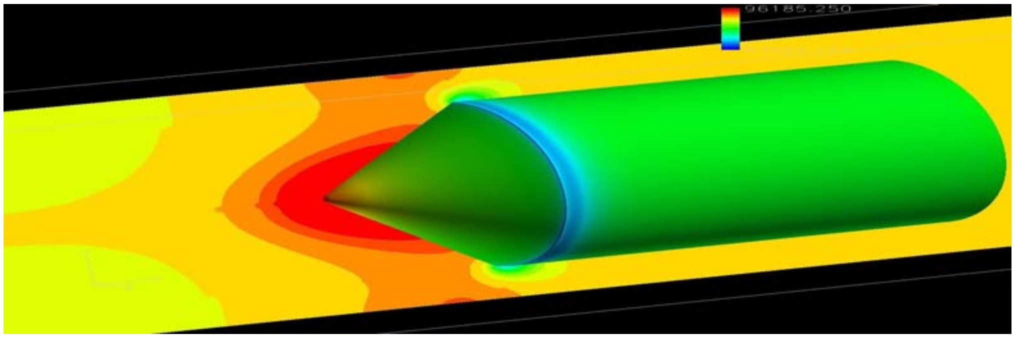


Figure-3.3:- The Pressure Contours

The flow strikes on the wall of bore after diverging from pig cone. Hence a larger pressure is achieved on the wall on the bore.

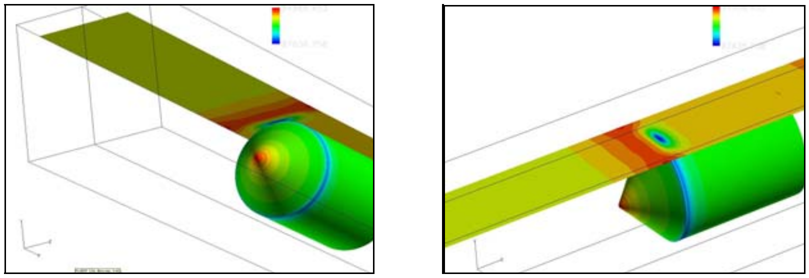


Figure-3.4, 3.5:- Pressure on the Wall of Bore

The pressure also varies at different planes as air and CO_2 jet moves towards the pig and it is maximum at pig nose**.**

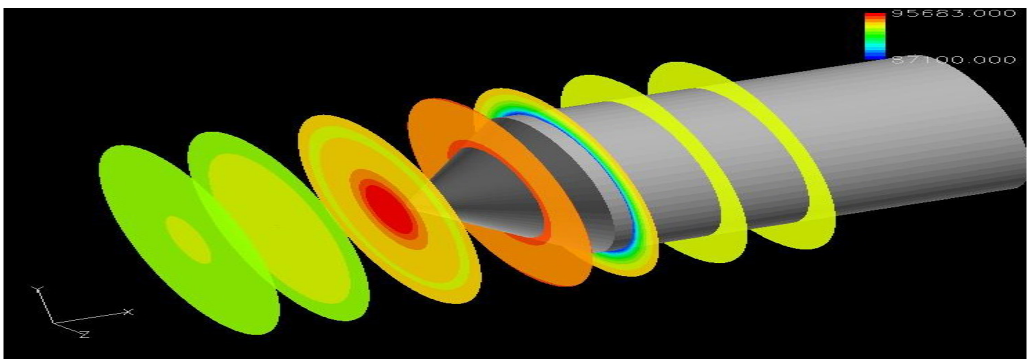


Figure-3.6:-Pressure Variation at Different Planes

The same results can be verified from the graph of pressure and the position of CO_2 and air as it travels in the bore, again the maximum pressure area is starting from the nose of the cone.

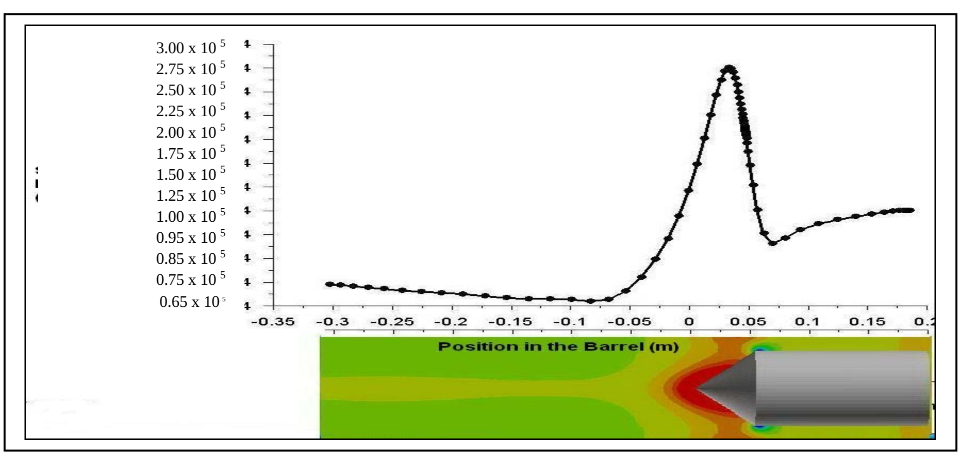


Figure- 3.7:- Pressure Vs Position In Bore

An over view of pressure distribution in respect of position in the bore can very well under stand from the figure above.

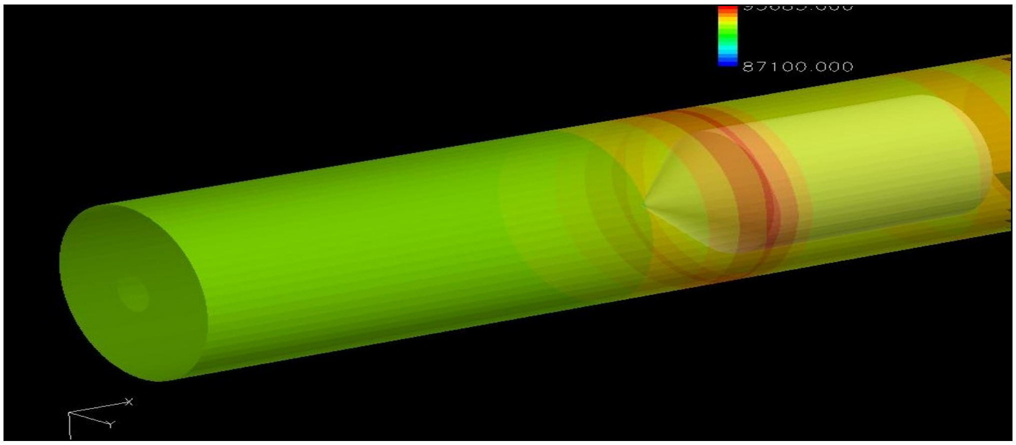


Figure- 3.8:-Pressure Distribution in the Bore

3.6.3 Velocity Vectors:-

Figure shows the velocity vectors in XY plane. These vectors show that the flow strikes on the wall of bore after diverging from pig nose. Hence a greater pressure is achieved on the wall on the bore.

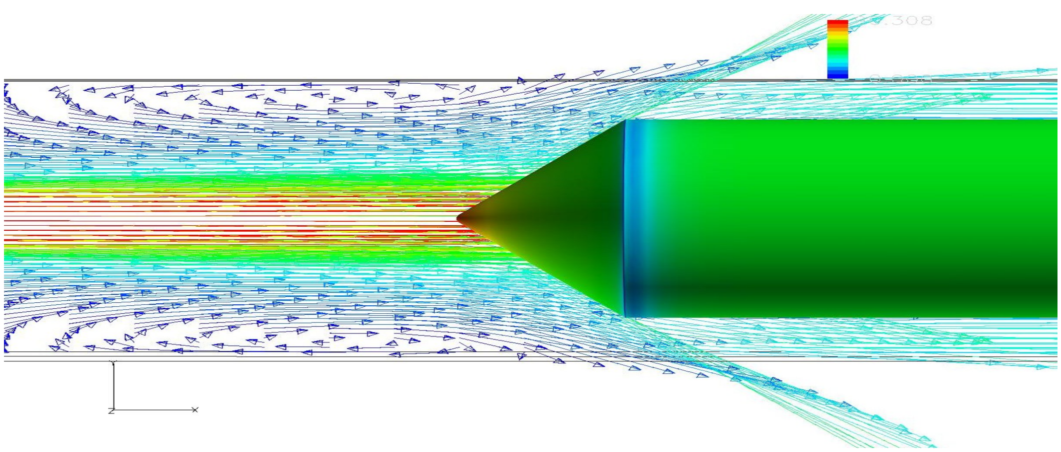


Figure-3.9:- Velocity Vectors

A circulation of flow is observed on the region behind maximum pressure area, that is, on the surface of the bore. Figure-8.11 clearly shows this circulation. The vector with greater length shows that it has greater velocity then those of shorter length

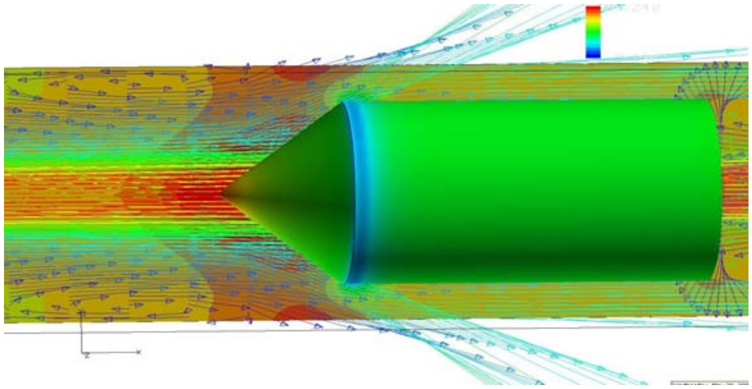
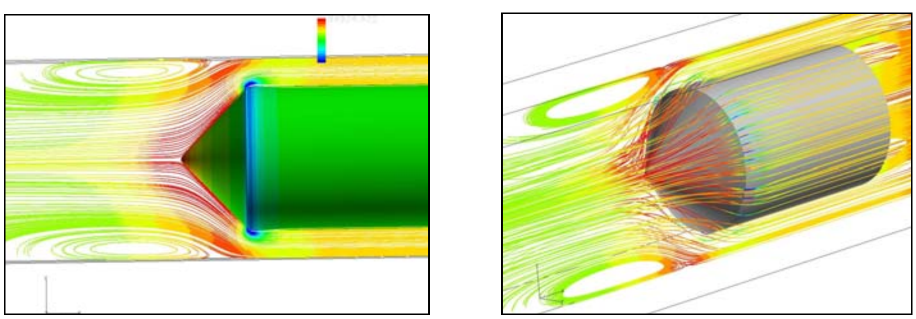


Figure-3.10:- Velocity Pressure Contours

Figure shows the pressure contours and velocity vectors on the same XY plane. A circulation of flow is also observed in this figure on the same region behind maximum pressure area, that is, on the surface of the bore.

3.6.4 Streamlines Plot:-

A streamlines plot is also made for better understanding of flow behavior. The streamlines colored by pressure show the same pattern of flow as achieved earlier. A strong circulation can also be observed in the streamline plot behind the maximum pressure region.



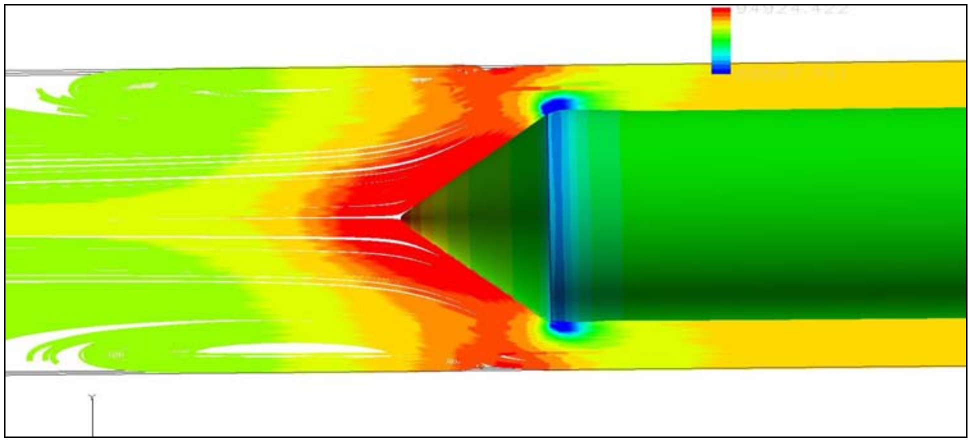


Figure-3.11, 3.12, and 3.13:- A Streamline Plot Colored With Pressure

3.7 Conclusion:-

CFD analyses have been performed to calculate the stress developed in the intelligent pig and gun bore due high velocities of CO_2 and air jet. It has been observed that for a maximum velocity of 180 m/sec, the stress developed in both the materials is far less than the yield stresses of the materials. CFD analyses also provided the complete behavior of fluid flow in the domain and its confirmed that a higher pressure value is achieved on the wall of the bore which is necessary to remove the contaminants.

CHAPTER-3

COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

3.1 Introduction:-

CFD is a tool which shows complete behavior of flow in any domain**.** Here CFD analysis is required for gun cleaning with dry ice before doing the practical.

The CFD analysis is used to calculate the effect of stresses generated by the jet of CO_2 & air on the face of pig & the wall of the bore. Our main concern is to calculate the maximum stress generated by jet of CO_2 & air at different velocities. From here we will confirm that these stresses are lesser than the allowable stresses of the gun bore & intelligent pig material. For our CFD analysis we assume that CO_2 is in gas form with greater density. In actual case, CO_2 is in solid form when thrown on the pig. Our problem is very much closer to fluid mechanics problem as solid CO_2 behaves nearly as fluid. The CFD analysis are carried out by assuming CO_2 as gas due to the same reason.

Thermal stresses are considered in Chapter 4.

3.2 Software Used:-

Following Software is used for our CFD analysis:-

a.	Grid Generation -	Gridgen 15.10
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c.	Post Processing-	Field View 10.0

3.3 Grid Generation:-

Gird generation is the primary requirement for CFD analysis. A 3 D structured grid was made for the analysis. The Grid was made by using

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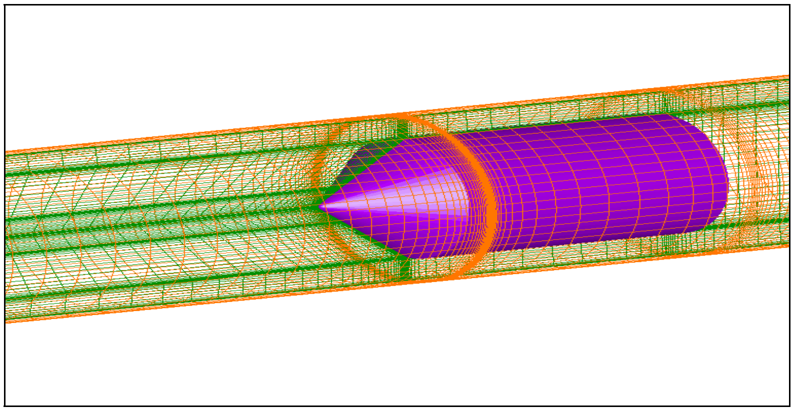

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$$\frac{\partial}{\partial t}(\rho\tilde{\nu}) + \frac{\partial}{\partial x_i}(\rho\tilde{\nu}u_i) = G_\nu + \frac{1}{\sigma_{\tilde{\nu}}}\left[\frac{\partial}{\partial x_j}\left\{(\mu + \rho\tilde{\nu})\frac{\partial\tilde{\nu}}{\partial x_j}\right\} + C_{b2}\rho\left(\frac{\partial\tilde{\nu}}{\partial x_j}\right)^2\right] - Y_\nu + S_{\tilde{\nu}} \tag{3}$$

Where

Gv is the production of turbulent viscosity.

Yv is the destruction of turbulent viscosity.

Sv is the user defines source term.

3.5 Solver Parameters & Boundary Conditions:-

The parameters used in CFD analysis are the same upon which actual practical will be performed. Boundary conditions and the domain are shown in the figure below. Field view 10 was used for post processing in the analysis. The conditions are:-

a. Diameter of the air and CO_2 Jet = 25.4 mm.

b. Velocity of the air and CO_2 Jet = 90 m/sec

c. Surface of the bore = no slip wall

d. Surface of the pig = no slip wall

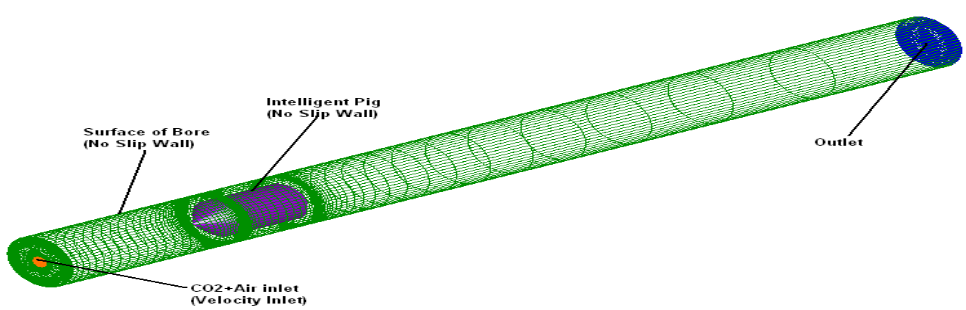

Figure- 3.2:-The Boundary Conditions

3.6 Results:-

With our the parameters discussed in our previous paragraphs, the CFD analyses are carried out which showed the complete behavior of the flow as under:-

3.6.1 Stress Calculations:-

3.6.1.1 Intelligent Pig:-

Material	Cu Alloy
Yield Stress	760MPa

Case-1:- **At velocity = 90 m/s**

Stress= σ =Force / Area

Area = π x $(.110)^2/4 = 9.489x10^{-3}$

Force = 13224 N

Stress = 1.393 MPa

The stress on the pig has far less value than yield stress of pig material.

Case-2:- **At velocity = 180 m/s**

Stress = σ = Force / Area

Area = π x $(.110)^2/4 = 9.489x10^{-3}$

Force = 15972 N

Stress = 1.7 MPa

The stress on the pig has far less value than yield stress of pig material in this case also.

3.6.1.2 Bore of Barrel:-

Material	discussed earlier
Yield Stress	900 MPa

Case-1:- **At Pressure = 2.85 bar**

Pressure= 2.85 bar

Diameter= 0.125 m

Thickness= 0.0127 m

Stress σ (hoop) = (pressure x diameter) /2x thickness

Stress σ (hoop) = 1.4 MPa

The stress on the bore has far less value than yield stress of bore material

Case-2:- **At Pressure = 3.5 bar**

Diameter= 0.125 m

Thickness= .0127 m

Stress σ (hoop) = 1.7 MPa

The stress on the bore has far less value than yield stress of bore material in ths case also.

3.6.2 Pressure Contours:-

The pressure contours showed that the maximum pressure was exerted on the nose of the pig and after striking the nose again the maximum pressure was found on the surface of the bore. Hence the maximum pressure of air and CO_2 jet was achieved on the surface of bore. Figure below shows pressure contours on the surface of the bore in XY plane. Maximum pressure was found on the nose of the pig and on the surface of the bore. It also indicates the low pressure at the edges of pig cone, due to the obvious reason of separation of flow

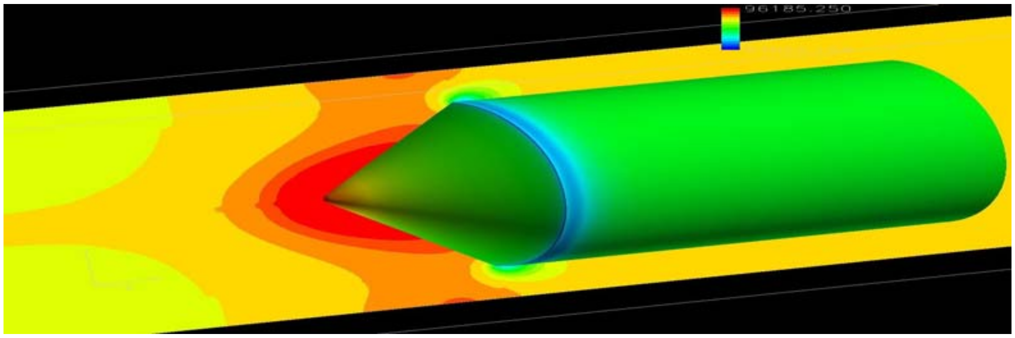

Figure-3.3:- The Pressure Contours

The flow strikes on the wall of bore after diverging from pig cone. Hence a larger pressure is achieved on the wall on the bore.

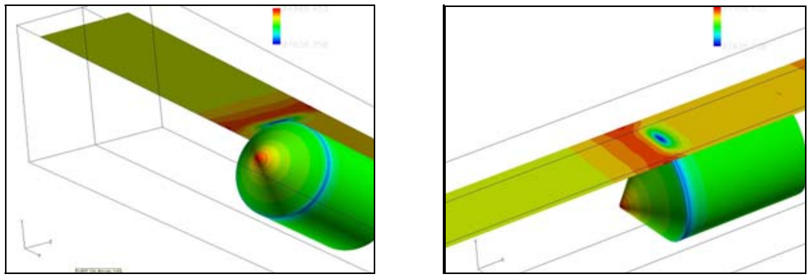

Figure-3.4, 3.5:- Pressure on the Wall of Bore

The pressure also varies at different planes as air and CO_2 jet moves towards the pig and it is maximum at pig nose**.**

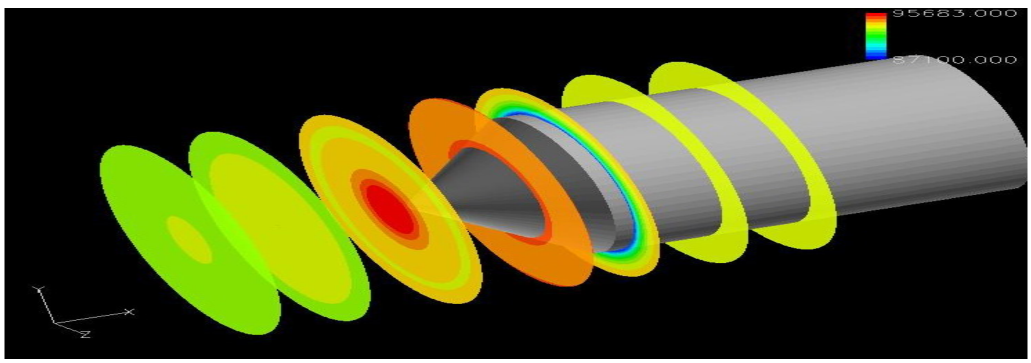

Figure-3.6:-Pressure Variation at Different Planes

The same results can be verified from the graph of pressure and the position of CO_2 and air as it travels in the bore, again the maximum pressure area is starting from the nose of the cone.

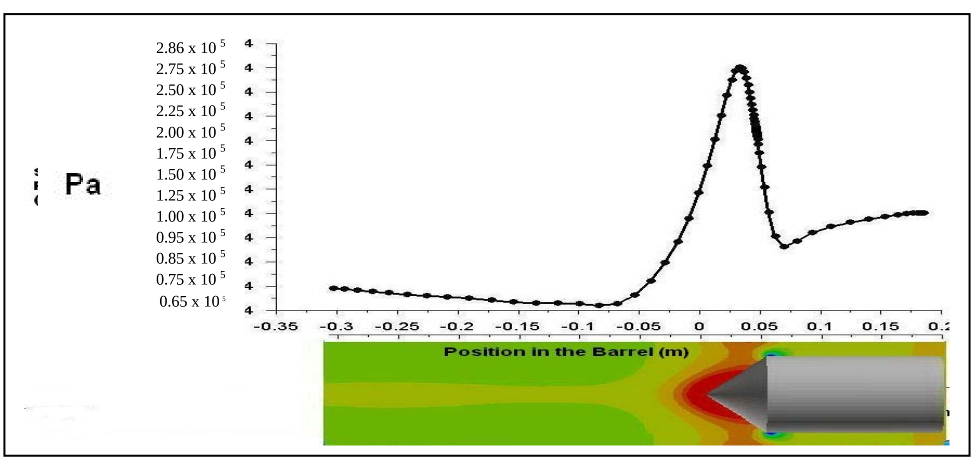

Figure- 3.7:- Pressure Vs Position In Bore

An over view of pressure distribution in respect of position in the bore can very well under stand from the figure above.

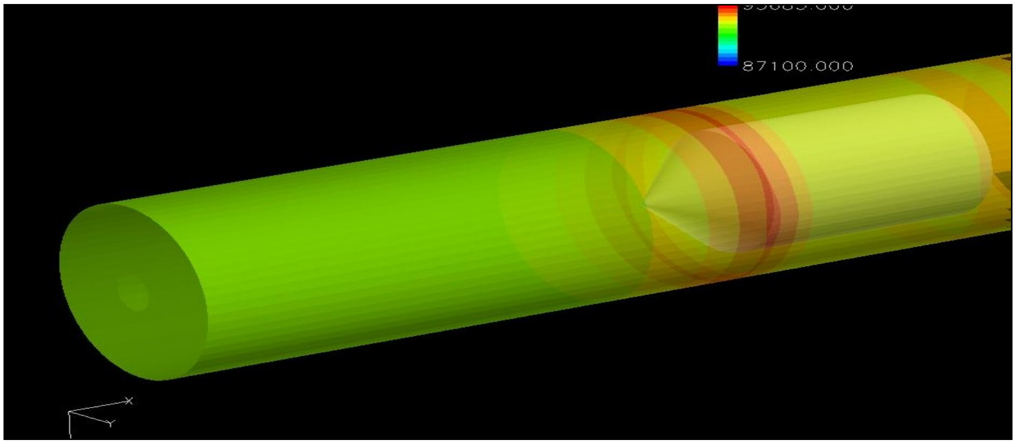

Figure- 3.8:-Pressure Distribution in the Bore

3.6.3 Velocity Vectors:-

Figure shows the velocity vectors in XY plane. These vectors show that the flow strikes on the wall of bore after diverging from pig nose. Hence a greater pressure is achieved on the wall on the bore.

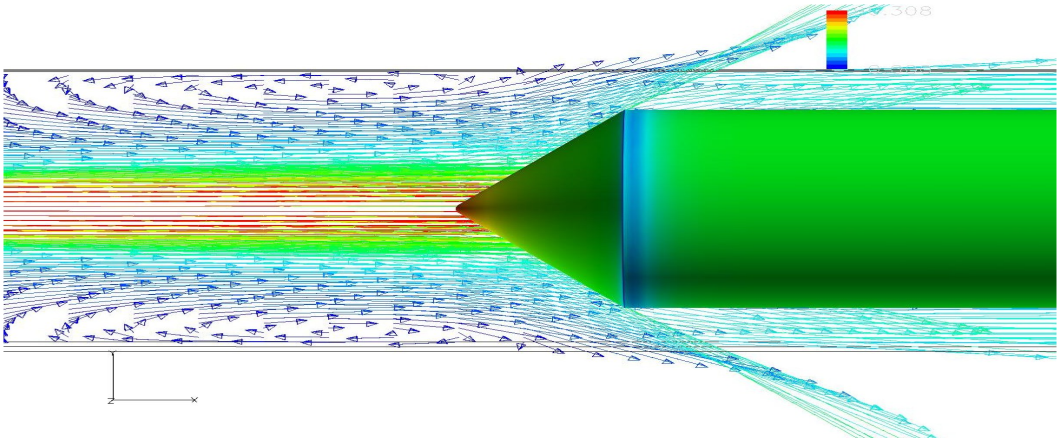

Figure-3.9:- Velocity Vectors

A circulation of flow is observed on the region behind maximum pressure area, that is, on the surface of the bore. Figure-8.11 clearly shows this circulation. The vector with greater length shows that it has greater velocity then those of shorter length

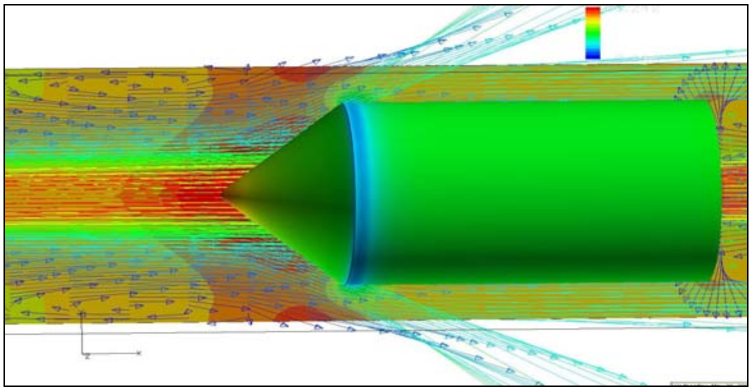

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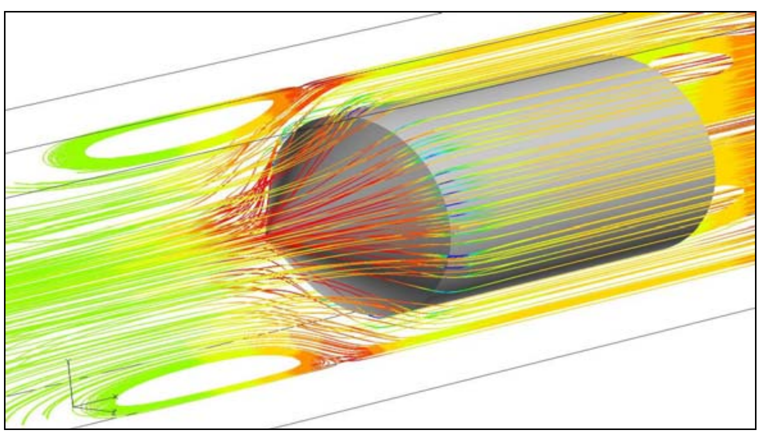
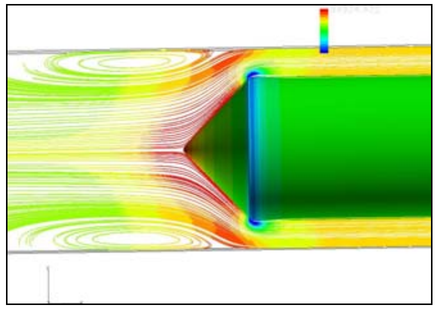
Figure shows the pressure contours and velocity vectors on the same XY plane. A circulation of flow is also observed in this figure on the same region behind maximum pressure area, that is, on the surface of the bore.

3.6.4 Streamlines Plot:-

A streamlines plot is also made for better understanding of flow behavior. The streamlines colored by pressure show the same pattern of flow as achieved earlier. A strong circulation can also be observed in the streamline plot behind the maximum pressure region.





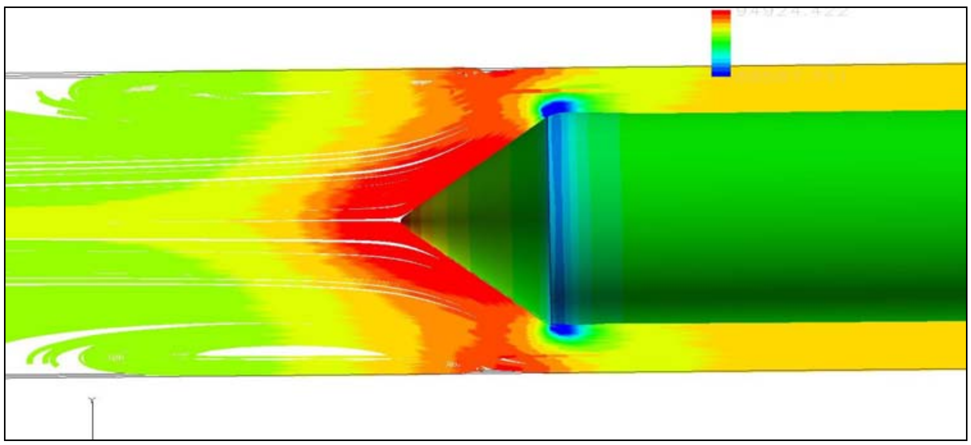


Figure-3.11, 3.12, and 3.13:- A Streamline Plot Colored With Pressure

3.7 Conclusion:-

CFD analyses have been performed to calculate the stress developed in the intelligent pig and gun bore due high velocities of CO_2 and air jet. It has been observed that for a maximum velocity of 180 m/sec, the stress developed in both the materials is far less than the yield stresses of the materials. CFD analyses also provided the complete behavior of fluid flow in the domain and it confirmed that a higher pressure value is achieved on the wall of the bore which is necessary to remove the contaminants.

CHAPTER-4

EFFECT OF DRY ICE ON PARENT MATERIAL

4.1 Introduction:-

In our practical / demonstration, it was the concern that low temperature of dry ice may change the thermal properties of parent material. There was a need to study the effect of low temperature on the parent material with respect to change in time. Here the study of the same aspect has been carried out in the manner that first, the experiment has been performed, then the same been confirmed with numerical solutions.

4.2 Experimental Approach:-

What is the dry ice blasting effect on the parent material? It is a common question. It is proven that the temperature decrease occurs on the surface only, so that there is no chance of thermal stress occurring in the parent metal. To prove this fact an experiment was performed with thermocouples which were placed into a piece of steel at varying depths up to 1.5 mm deep. The side and top view of piece of steel along with the placement of thermocouples placed at the depths of 0.5, 1.0, 1.5, are shown in the figure 5.1.

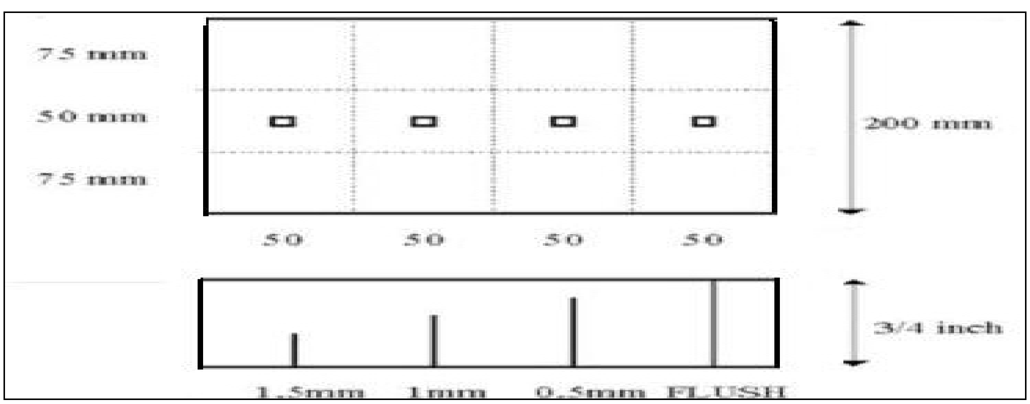


Figure- 4.1:- Thermocouples at Varying Depths [5]

A dry ice blast nozzle was constantly moved over the piece of steel for 30 seconds (a relatively long time for this process) and the thermocouples recorded the changing temperatures at the varying depths as discussed. As shown in figure 8.2, the surface-mounted thermocouple shows a temperature drop each time the blast nozzle passed directly upon it (50° C in about 5 seconds). In contrast, the thermocouples imbedded at various depths in the parent material recorded a slow drop in temperature corresponding to the top plate temperature drop. The thermocouple placed at 1.5mm deep only dropped 10°C after 30 seconds. This curve illustrates that the "Thermal Shock" occurs only at the surface where the coating or contaminate is bonded to the substrate and has no drastic effect on the parent material.

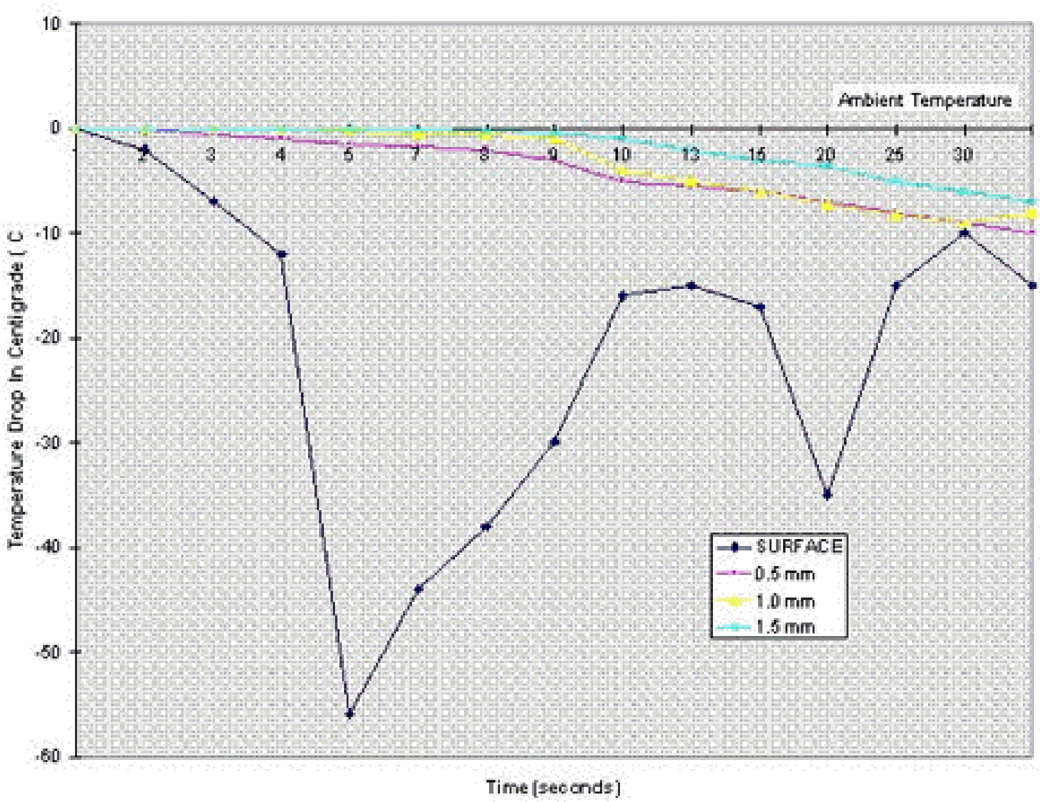


Figure-:4. 2 Temperature Response of Thermo Couples Placed at Various Depths in the Parent Material [2]

4. 3 Numerical Approach:-

4.3.1 Numerical Approach-1(Thermal Stress vs. Temperature):-

Another way to looking at thermal stress in material by the use of dry ice blasting in the molded rubber industry. Here, hot steel molds operating at 300+°F are blasted with -109°F dry ice particles. The temperature difference between the hot mold and cold dry Ice will not cause cracking. The reasons for this phenomenon are, first, as above, the temperature gradient occurs at the surface. Second, the thermal stresses involved are much less than those required during normal heat treatment. [2]The thermal stress due to a temperature differential can be proved by equation-1, where *σy* is stress (psi), *ΔT* is temperature gradient (°F),*α* is coefficient of expansion and *v* is Poisson's Ratio[22].

$$\sigma = \frac{E\alpha\Delta T}{1-\nu} \qquad (1)$$

The corresponding parameter values are

Here for steel

$E=30 \times 10^{6}$

$\alpha = 5 \times 10^{-6}$

$v=0.33$

$$\sigma y = \frac{((30\times 10^{6}) \times (5\times 10^{-6}) \times \Delta T)}{(1-0.33)} \qquad (2)$$

And the thermal stress (psi) is

$$\sigma y = 224\Delta T \qquad (3)$$

Here we consider two cases

4.3.1.1 Case-1

The mold temperature be braught to ice temperature i.e.

T_2 = 32 ^{0} F (an unrealistic extreme) &

T1= -109^0F (dry ice temperature)

ΔT= 141^0 F

σy= 31584 psi [by putting the values in (3)]

This shows the value of low tensile stress. This value is again less than the yield point of steel

4.3.1.2 Case-11

The mold temperature be brought to actual temperature i.e.

T_2 = 350^0F &

T1= -109^0F (dry ice temperature)

ΔT= 459^0 C

σy= 102800 psi [by putting the values in (3)]

This value is again less than the yield point of steel

Again, these thermal stresses would be far less than those encountered during normal heat treatment where the temperature differentials would exceed 500 °F / 260°C. [5]

Even at high impact velocities and direct "head-on" impact angles, the kinetic effect of solid CO_2 / dry ice particles is minimal when compared to other media (grit, sand, etc.).Even at high impact velocities and direct "head-on" impact angles, the kinetic effect of solid CO_2 / dry ice particles is minimal when compared to other media (grit, sand, etc.) This is due to the relative lack of hardness of the dry ice particles and the almost instantaneous phase change to a gas on impact, which effectively provides an almost nonexistent coefficient of restitution in the impact equation. Because dry ice blasting is considered non-abrasive and relies on the thermal effects discussed above, the process may be applied to a wide range of materials without damage. Soft metals such as brass and aluminum cladding can be dry ice blasted for the removal of coatings or contaminates without creating surface stresses (pinging), pitting, or roughness [2]

4.3.2 Numerical Approach - 2:-

Consider a piece of solid maintained at some initial temperature *Ti*. The surface temperature is suddenly dropped and maintained at a temperature *To* and we require an expression for the temperature distribution in the solid as a function of time. This temperature distribution may subsequently used to calculate heat flow at any *x* position in the solid as a function of time. For constant properties, the differential equation for the temperature distribution *T(x, τ)*

$$\frac{\partial^2 T}{\partial x^2} = \frac{1 \partial T}{\alpha \, \partial \tau} \qquad (4)$$

The boundary and initial conditions are

T(x, 0) = Ti

T(0, τ) = To for τ > 0

This problem has been solved by the Laplace Transformation Technique. The solution is:-

$$\frac{T(x, \tau) - To}{Ti - To} = erf \, \frac{x}{2\sqrt{\alpha \tau}} \qquad (5)$$

The same equations will be used in our case study in subsequent paragraphs. [23]

4.4 Case Study:-

Here we have a piece of steel with following data/ specification for which we have to calculate the temperature at three different locations, that is, x= 0.5mm. x=1.0mm and x=1.5mm form 1- 30 seconds.

Thermal conductivity	*(k)* = 45 W/mK
Thermal diffusivity	(α) = 1.4 x 10 -5 m^2/s
Initial temperature	*(Ti)* = 25°C
Applied temperature (dry Ice)	*(T0)* = -78°C

Now consider the case at distance x = 0.5 mm

Applying the equation (5) for time = 1 sec

We calculate first

$$\frac{x}{2\sqrt{\alpha\tau}} = \frac{0.0005}{(2)[(1.4\times10^{-5})(1)]^{1/2}} = 0.066815$$

The error function for 0.066815 is determined from Appendix A [24]. The error functions for all the values of $\frac{x}{2\sqrt{\alpha\tau}}$ has not been available in Appendix A [54]. An interpolation has been done to calculate the remaining values. This same has been done by making a function between factor $\frac{x}{2\sqrt{\alpha\tau}}$ and *erf* $\frac{x}{2\sqrt{\alpha\tau}}$ by using the available values of these from Appendix A [54]. We consider

$$\frac{x}{2\sqrt{\alpha\tau}} = x$$

and $$erf\ \frac{x}{2\sqrt{\alpha\tau}} = y$$

Then our interpolation equation became

$$y = 0.086x^4 - 0.4008x^3 + 0.003x^2 + 1.1283x - 9E\text{-}07$$

Using the same interpolation equation the error function for above value is calculated as

$$= erf\ \frac{x}{2\sqrt{\alpha\tau}}$$

$$= \text{erf}\ (0.066815)$$

$$= 0.07527$$

The temperature of piece can now be found by using the equation (5) as

$$T\ (x, \tau) = To + (Ti - To)\ \text{erf}\ \frac{x}{2\sqrt{\alpha\tau}}$$

$$T\ (0.5, 1) = -78 + \{25 – (-78)\}\ (0.075279)$$

$$T\ (0.5, 1) = -70.2463^{o}\ C$$

In the similar manner calculations has been performed for three different depths (x = 0.5mm, x= 1.0mm and x=1.5mm) with different times ranging from 1 second to 30 seconds, shown as in Tables1,2, and 3.

Time(sec)	$\frac{x}{2\sqrt{\alpha\tau}}$	$erf\ \frac{x}{2\sqrt{\alpha\tau}}$	Temp (C-deg)
0			
1	0.06681531	0.07527889	-70.24627436
2	0.047245559	0.053261789	-72.51403578
3	0.038575837	0.043496952	-73.51981399
4	0.033407655	0.03767334	-74.11964594
5	0.029880715	0.033698139	-74.52909166
6	0.027277236	0.030763313	-74.83137881
7	0.025253814	0.028482123	-75.06634138
8	0.02362278	0.026643164	-75.25575408
9	0.02227177	0.025119837	-75.41265674
10	0.021128856	0.023831088	-75.54539797
11	0.020145574	0.022722296	-75.65960347
12	0.019287919	0.021755137	-75.75922087
13	0.018531233	0.020901817	-75.84711286
14	0.017857143	0.020141624	-75.92541278
15	0.017251639	0.019458764	-75.9957473
16	0.016703828	0.018840957	-76.0593814
17	0.016205093	0.01827849	-76.11731554
18	0.01574852	0.017763565	-76.17035282
19	0.015328483	0.017289841	-76.21914637
20	0.014940358	0.016852102	-76.2642335
21	0.014580296	0.016446011	-76.30606089
22	0.014245072	0.016067929	-76.34500329
23	0.013931955	0.015714779	-76.3813778
24	0.013638618	0.015383934	-76.41545477
25	0.013363062	0.015073143	-76.4474663
26	0.01310356	0.014780457	-76.47761296
27	0.012858612	0.014504184	-76.50606905
28	0.012626907	0.014242846	-76.53298689
29	0.012407292	0.013995143	-76.55850025
30	0.012198751	0.01375993	-76.58272717

Table- 4.1:- Temperature Calculations for x=0.5 mm

Time(sec)	$\frac{x}{2\sqrt{\alpha\tau}}$	$erf\ \frac{x}{2\sqrt{\alpha\tau}}$	Temp (C-deg)
0			
1	0.133630621	0.150108642	-62.53880986
2	0.094491118	0.106343857	-67.04658268
3	0.077151675	0.086891723	-69.05015257
4	0.06681531	0.07527889	-70.24627436
5	0.05976143	0.067347204	-71.06323801
6	0.054554473	0.061489045	-71.66662832
7	0.050507627	0.056934315	-72.13576558
8	0.047245559	0.053261789	-72.51403578
9	0.04454354	0.050219099	-72.82743276
10	0.042257713	0.047644615	-73.09260462
11	0.040291148	0.045429389	-73.32077297
12	0.038575837	0.043496952	-73.51981399
13	0.037062466	0.041791841	-73.69544037
14	0.035714286	0.040272718	-73.85191
15	0.034503278	0.038908058	-73.99247006
16	0.033407655	0.03767334	-74.11964594
17	0.032410186	0.036549172	-74.23543524
18	0.031497039	0.035519984	-74.34144162
19	0.030656967	0.034573113	-74.43896938
20	0.029880715	0.033698139	-74.52909166
21	0.029160592	0.032886402	-74.61270057
22	0.028490144	0.032130634	-74.69054468
23	0.027863911	0.031424685	-74.7632574
24	0.027277236	0.030763313	-74.83137881
25	0.026726124	0.030142014	-74.89537259
26	0.026207121	0.029556899	-74.95563943
27	0.025717225	0.029004587	-75.01252758
28	0.025253814	0.028482123	-75.06634138
29	0.024814583	0.027986911	-75.11734812
30	0.024397502	0.027516664	-75.16578365

Table- 4.2:- Temperature Calculations for x=1.00 mm

Time(sec)	$\frac{x}{2\sqrt{\alpha\tau}}$	$erf\ \frac{x}{2\sqrt{\alpha\tau}}$	Temp (C-deg)
0			
1	0.200445931	0.224390407	-54.88778807
2	0.141736677	0.159147363	-61.60782163
3	0.115727512	0.130115101	-64.59814461
4	0.100222966	0.112765727	-66.38513009
5	0.089642146	0.100907845	-67.60649201
6	0.081831709	0.092145629	-68.50900021
7	0.075761441	0.085330515	-69.2109569
8	0.070868339	0.079833876	-69.77711078
9	0.06681531	0.07527889	-70.24627436
10	0.063386569	0.071424115	-70.64331612
11	0.060436722	0.068106754	-70.98500436
12	0.057863756	0.065212507	-71.28311182
13	0.055593699	0.062658451	-71.54617959
14	0.053571429	0.060382767	-71.78057505
15	0.051754917	0.058338301	-71.99115504
16	0.050111483	0.056488374	-72.18169747
17	0.048615279	0.054803969	-72.35519115
18	0.047245559	0.053261789	-72.51403578
19	0.04598545	0.05184288	-72.66018332
20	0.044821073	0.050531651	-72.79523997
21	0.043740888	0.049315135	-72.92054113
22	0.042735216	0.048182452	-73.03720742
23	0.041795866	0.047124397	-73.14618714
24	0.040915854	0.046133117	-73.24828891
25	0.040089186	0.045201873	-73.34420706
26	0.039310681	0.044324839	-73.43454157
27	0.038575837	0.043496952	-73.51981399
28	0.03788072	0.042713786	-73.60048009
29	0.037221875	0.041971454	-73.6769402
30	0.036596253	0.041266528	-73.74954758

Table- 4.3:- Temperature Calculations for x=1.5mm

The graph of above calculations showing the drop of temperature is as under:-

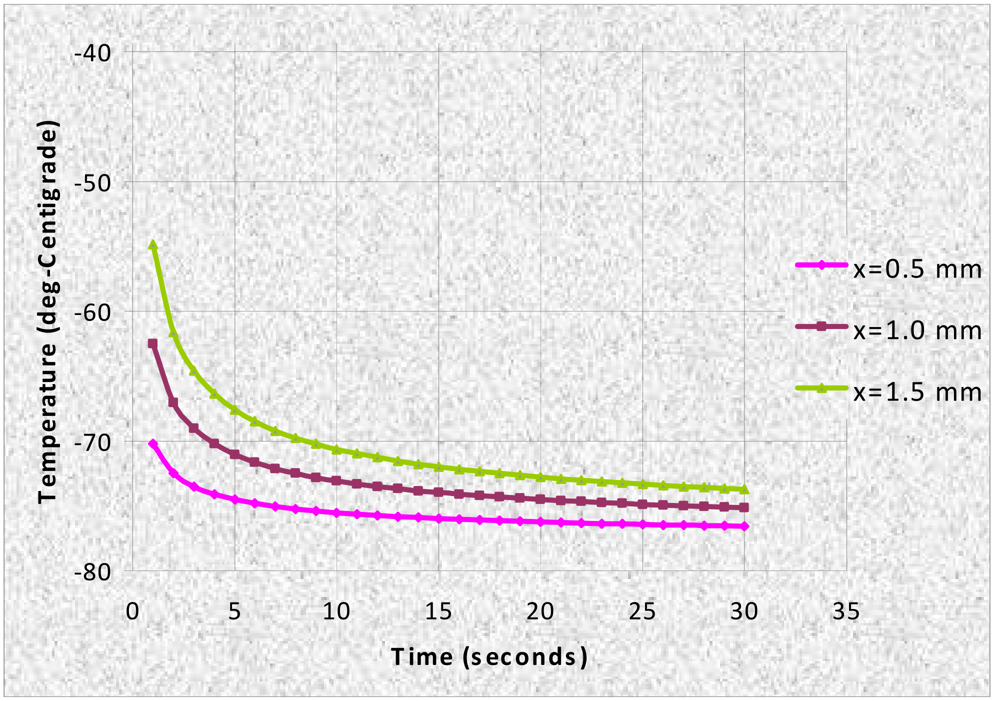


Figure- 4.3:- Temperature Drop at Various Depths

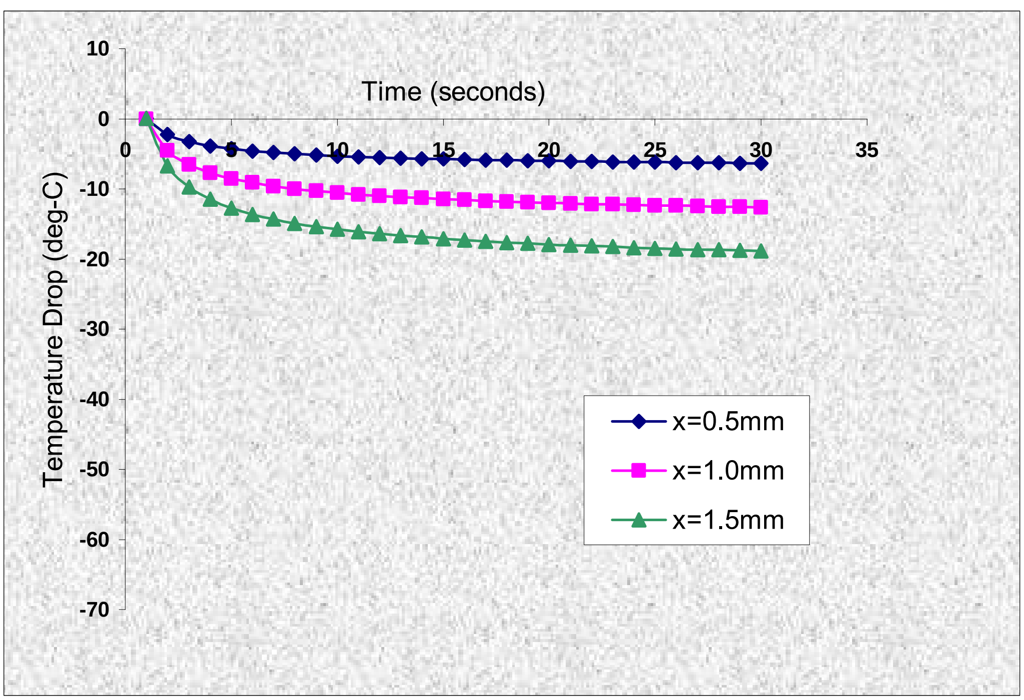


Figure- 4.4:- Temperature Drop at Various Depths

Another graph of our Numerical Approach-2 showing the temperature drop similar to the graph of Experimental Approach showing the same result is shown in figure 4.4.

4.5 Conclusion:-

As our experimental results showed that the temperature drop for a steel piece at different depths is in the range of 10^{o}C for 30 seconds time. Our numerical results satisfies the experimental results in which the temperature drop is within 8^{o}C to 15^{o}C.This little variation can be due to the experimental errors in calibration of the equipment or in thermocouple readings. Figure 5.3 and 5.4 show the same temperature drop in steel piece at various depths basing upon the data obtained from the tables already discussed.

CHAPTER-5

THE EXPARIMENT OF GUN BORE CLEANING

5.1 Introduction:-

Cleaning of gun bore with dry ice has never been used in any of the Amy in the word. It was the first time that the gun bore was being cleaned with dry ice blasting. It is brand new technology as for as Pakistan is concerned. No such specialized equipment/man power is available in Pakistan. A private firm named PAIE [16] was located and consulted for the demonstration. PAIE are the branch of MYCON Gmbh [19] (a German company working in dry ice blasting in Pakistan) .

5.2 Selection of Gun Barrel:-

Figure-5.1:- A 125mm Gun Barrel

A gun barrel of 125 mm bore was selected for test/trial purpose. The reason for selection of 125 mm bore was, that , its are being manufactured in Pakistan, The composition of gun martial is as under [17]:-

C	**0.310**
Mn	**0.195**
Si	**0.200**
S	**0.001**
P	**0.005**
Ni	**3.510**
Cr	**1.455**
Mo	**0.420**
V	**0.190**
Cu	**0.050**
Al	**0.011**
Fe	**Rest**

For the availability of gun barrel, Heavy Industries Taxila (HIT) was approached. The gun barrel was provided by HIT. The requirement was that barrel should be the dirtiest, having a lot much containment. The same barrel [18] **was** provided for the demonstration purpose by HIT**.**

5.3 Equipment for Dry Ice Blasting:-

It was very first time that gun barrel was being cleaned with dry ice blasting. The PAIE were not very much sure about the successful conduct of the demonstration. The PAIE contacted with their principal, MYCON Gmbh at Germany. The whole problem was discussed with them. After the deliberation of about three months, the MYCON Gmbh provided the following equipment:-

5.3.1 An Intelligent Pig: -

It was a hollow circular piece of a composite martial with metallic nose, screwed on the face of composite material. Its dimensions are shown in the figure. Its function was to divert the mixture of dry ice and air (after striking the nose) to the internal bore of the barrel. The nose was having a small hole on its tip through which a wire was fixed to control the rearward movement of the pig under high pressure of dry ice and air. The pig was deliberately made by a soft composite material so that it should not damage the bore while contacting it.

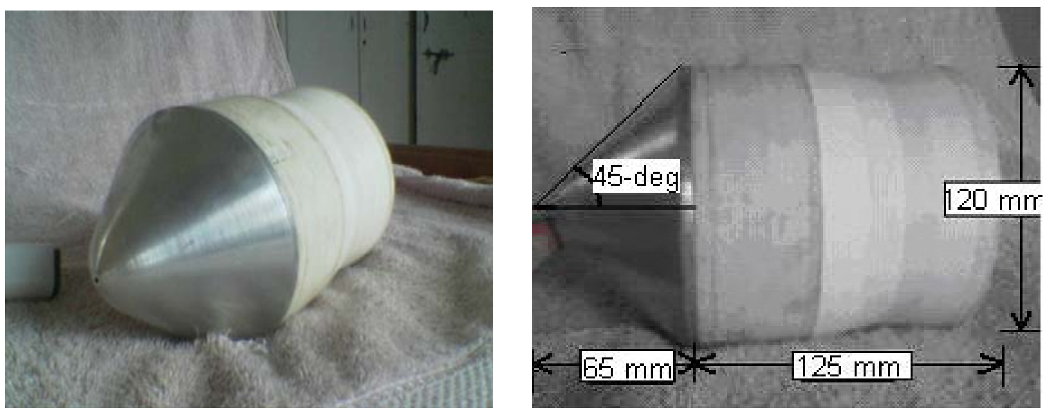


Figure-5.2:- An Intelligent Pig

Figure-5.3:-An Un Screwed Intelligent Pig

5.3.2. Sealing Plug: -

A Sealing Plug as shown in the figure was also provided. Its function was to seal the face of the bore and connect the bore with dry ice and air mixing gun. Its complete working can be very well under stood from the figure. [19]

Figure-5.4:- A Sealing Plug

5.3.3. Air Compressor: -

Since high pressure air is required in the process, a heavy duty compressor with can produce pressure up to 150 bars was used in the demonstration.

5.3.4. CO_2 Plant: -

A commercially available CO_2 plant was used which had the ability to convert gas CO_2 to solid CO_2 on line/on the spot.

5.4 Scheme of the Process:-

Figure-5.5:- Barrel Cleaning Process

5.5 Conduct of Practical / Demonstration:-

The demonstration was conducted in Gun Factory at Heavy Industries Taxila (HIT), in the presence of the experts of HIT. The whole equipment as mentioned above was brought to HIT. The CO_2 plant was mounted on a 2 .5 ton truck and heavy duty air compressor was jeep towed. The barrel, placed on a stand, was provided by HIT (Gun Factory) having the following specifications.

a. Length - 18 feet

b. Diameter of the bore - 125 mm

c. Material of the barrel - Already discussed

d. Contaminants - Dirt, Dust, Lubricants, Copper Carbon

The demonstration was conducted in the following manner:-

a. The back of sealing plug was fitted by a gun having two connected pipes, one with CO_2 plant and 2nd with air compressor as shown in the figure 7.5.

b. The front of the sealing plug was fitted with face of the barrel.

c. Before doing the step ‘b’, the intelligent pig, fastened with a wire from the front of the pig cone, was place in the bore.

d. The dimension of the intelligent pig has already been discussed.

e. The clearance between the bore of the barrel and intelligent pig was given 0.5 mm by the manufacture of the system.

f. The pressure and CO_2 quantity were controlled by the knobs fitted with the gun and further connected with sealing plug which was fixed with the bore.

g. Dry ice and high pressure air, after striking the cone of the pig, dispersed and struck to the wall of the bore. Thus dropping the temperature of the containments, producing crack and finally washing away the contaminants by high pressure air.

h. The wire attached with the intelligent pig was gradually loosened till the length of the barrel and the completion of the cleaning process.

i. The total time to clean the barrel was only 5 to 10 minutes.

j. Since these was no numerical method to determine the extent of clean/contaminant’s removal. Only visual inspection method is used with the help of bore scope discussed in last chapter.

k. Photos of bore at various distances of length were taken before and after the cleaning. The visual comparison was made by the experts of HIT and results were established.

Figure-5.6:- Barrel Cleaning in Process

CHAPTER-6

OBSERVATIONS AND RESULTS

6.1 Observations:-

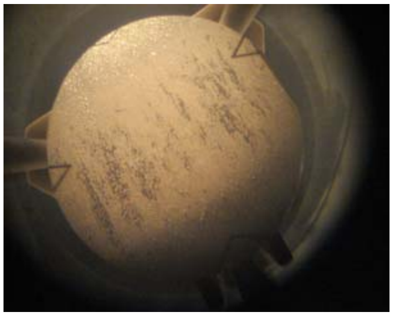
The gun barrel provided for the demonstration/ practical purpose was having registered number 2007-125P-003. It had fired a total of 250 rounds of ammunition. It was the dirtiest available barrel. At various distance of the length of barrel the photograph were taken through bore scope before cleaning the barrel. After the clean the photographs were again taken on the same distances. Both the photos were compared and difference of cleanliness was determined in % cleaning. As there is no other method of determining the extent of cleaning is available less the visual inspection. The results/observations are as:-

S/NO: - 1

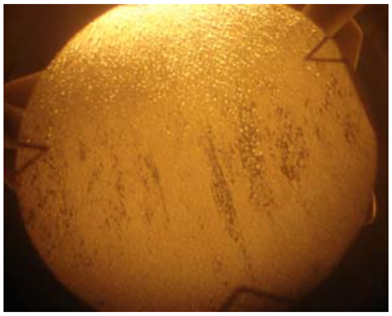
DISTANCE: - 17'

CONTAMINENTS : -

	%AGE CLEANING
Carbon -	60
Dirt /Dust -	100
Lubricants -	100
Copper -	100



Before



After

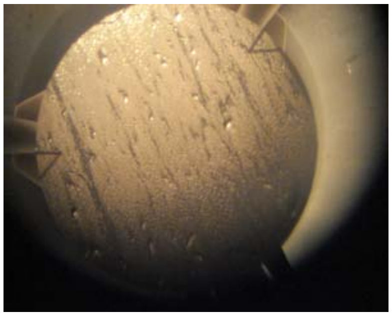
Figure-6.1:- Barrel Cleaning

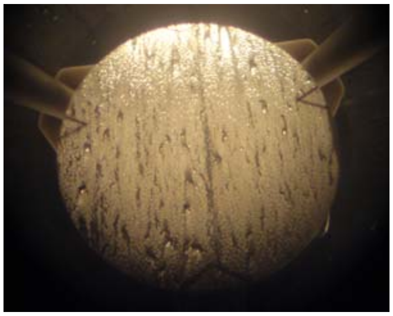
S/NO: - 2

DISTANCE: - 15’

CONTAMINENTS: -

	%AGE CLEANING
Carbon -	70
Dirt /Dust -	100
Lubricants -	100
Copper -	100





Before **After**

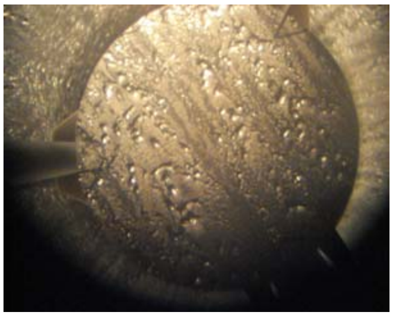
Figure-6.2:-Barrel Cleaning

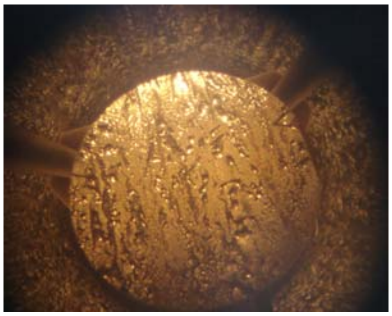
S/NO: - 3

DISTANCE: - 13’

CONTAMINENTS : -

	%AGE CLEANING
Carbon -	60
Dirt /Dust -	100
Lubricants -	100
Copper -	100





Before **After**

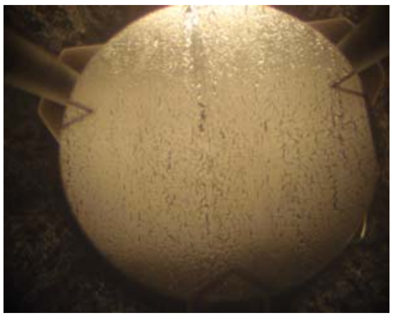
Figure-6.3:-Barrel Cleaning

S/NO: - 4

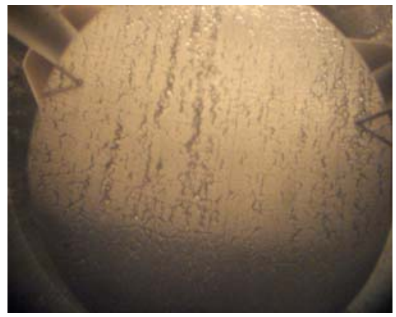
DISTANCE: - 11’

CONTAMINENTS: - %AGE CLEANING

Carbon -	70
Dirt /Dust -	100
Lubricants -	100
Copper -	100



Before



After

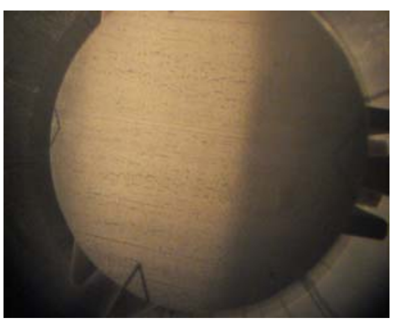
Figure-6.4:-Barrel Cleaning

S/NO: - 5

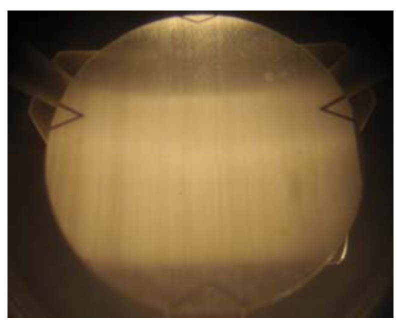
DISTANCE: - 11’

CONTAMINENTS: - %AGE CLEANING

Carbon -	60
Dirt /Dust -	100
Lubricants -	100
Copper -	100



Before



After

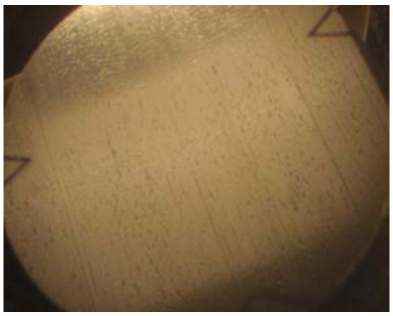
Figure-6.5:-Barrel Cleaning

S/NO: - 6

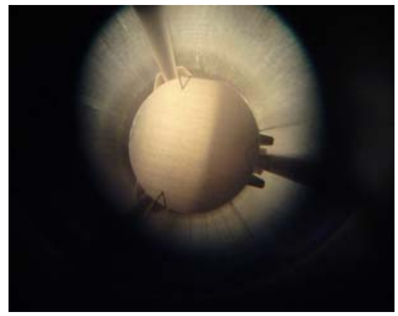
DISTANCE: - 9'

CONTAMINENTS: - %AGE CLEANING

Carbon -	70
Dirt /Dust -	100
Lubricants -	100
Copper -	100



Before



After

Figure-6.6: - Barrel Cleaning

6.2 Results:-

6.2.1 Removal of contaminants:-

a.	Carbon	60-70%
b.	Copper	100%
c.	Dirt/dust	100%
d.	Lubricants	100%
e.	Others	100%

6.2.2 Time of cleaning 5-10 minutes

6.2.3 Amount of CO_2 used 20 Kilograms

6.2.4 No of persons employed 3-4 Person

DISCUSSION

a. From our literature review we have reached the conclusion that dry ice can remove almost all the contaminants on parent material.

b. Various methods of gun bore cleaning are being utilized throughout the world basing upon pull through idea.

c. Gun bore cleaning through dry ice blasting has never been used in any of army in the world.

d. The problem in using dry ice blasting was that at -78^o C, the thermal properties of parent material may change but experiment performed in Chapter 4 shows that there is no effect of dry ice on parent material. The same has been confirmed through numerical analysis in the same chapter. So it can be used with gun bore safely.

e. CFD analysis has been carried out to calculate the stress developed on intelligent pig and gun bore due to high velocity of CO_2 and air jet. The CFD analysis showed that stress developed are far less than the yield stresses of both the material of the pig and the bore. Moreover the CFD analysis showed us the complete behavior of flow especially the pressure contours. Hence it is very much safe to use with gun barrel.

f. The practical was carried out at Heavy Industries Texila (HIT) with the team and equipment of a private firm PAIE.

g. Photos of gun bore at various distances were taken before cleaning and compared with the photos taken after the clean. The percentage cleaning was sentenced by the experts of HIT.

h. All the contaminants were removed 100% less the carbon which was removed only 60 – 70%.

i. The reason for not removal of carbon contaminants may be that it was one time cleaning due to unavoidable circumstances like being first time conducted and lack of experience in the field. This may improve by using the same technique various times.

j. The other reason may be that CO_2 and air may diverge before reaching the nose of the pig as the distance is being increased between the sealing plug and rearward moving intelligent pig. Due to this reason solid CO_2 and air may not work 100% efficiently on the wall of the bore after striking the nose of the pig.

k. In practical, solid CO, (-78C) was used for 5 to 10 mins which is a very large time. This is happened due to the reason that the test was being first time conducted without any previous experience. This can be improved by frequently using the same technique and getting some experience in the field.