BUREAU OF INDIAN STANDARDS

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Learning Science via Standards



PVC Pipes

Lesson 39

July 2023





STANDARDS CLUB

BUREAU OF INDIAN STANDARDS

Nurturing Young Minds as Ambassadors of Quality and Standards



Foreword

Everything around us, whether natural phenomena or manmade products can be explained through science. The product which are used in our daily life are outcome of conscious efforts by the mankind to fulfil and exceed the needs of the present and demands of the future. Students are taught science as part of their school curriculum, to enable them to understand the various scientific laws and principles and also to inculcate the habit of exploring the world through the lens of science. Quality characteristics of any product or service are decided based on the stated and implied needs and are generally described in a document called 'Standard'. Science and standards are inseparable and integral aspect of any product.

Bureau of Indian Standards (BIS), the national standards body of India, is mandated for establishment and promotion of standards and creating a quality ecosystem in the country. This is achieved through developing Indian Standards on products and services through the active involvement of relevant stakeholders and dissemination of information of such standards for their use and implementation across all sectors of economy. Academia, as an important stakeholder of BIS, has been contributing towards development of standards through research activities and providing inputs related to technological advancements in product development, their characteristics and use as well as methods of tests. BIS, on its part has also been promoting standards in academia through a variety of programmes. This has since been institutionalized in the form of "Standards Clubs" which are being established in educational institutions across India to nurture the young minds as ambassadors of quality and standards and prepare them for dealing with these aspects in future.

In this initiative of BIS, called "Learning Science via Standards", a series of Lesson Plans are made elaborating the various scientific concepts, laws and principles to help students understand their practical applications via standards. The series comprises of a variety of subjects for insights into the scientific laws and principles and relating them to the quality characteristics of products used in day-to-day life. First 10 Lesson Plans in the series are released on the occasion of World Consumer Rights Day on 15 Mar 2023. Second Set of 10 Lesson Plans were released on 10 Jun 2023 by Hon'ble Minister of State during the Governing Council Meeting of BIS.

The Lesson Plans are expected to serve as a useful tool for the teaching fraternity for imparting knowledge on scientific laws and principles through their practical applications in activities and products around us and facilitate an interactive learning experience for the students.

PVC Pipes





Before the invention of plastic, the only substances that could be molded were clays (pottery) and glass. The problem with these substances is that they are heavy, low strength and brittle. Metal on the other hand is strong and tough but needs very high temperatures to melt and cast into shapes. The metal pipes that have been used for potable water supply were prone to corrosion. Also, the grooves created due to corrosion can also provide a breeding ground for certain bacteria. The metal pipes are heavier and difficult to handle and assemble.

The newly invented plastic material was corrosion resistant, light, flexible, inexpensive, good for insulation and easier to handle. Plastics made possible the development of computers, cell phones, and most of the lifesaving medical equipment like IV tubes. For food producers and retailers, plastic is an indispensable packaging material. It also promoted food safety and shelf life and facilitates the transport and use of products. The world's first fully synthetic plastic was Bakelite which was invented in 1907 by Leo Baekeland. Global plastics production was estimated to be 405 million metric tons in 2022 with annual growth of 4%. Many varieties of plastic invented like Polyethylene (HDPE & LDPE), Polyvinyl Chloride (PVC), Polypropylene (PP) etc. are now widely used for variety of applications.



1. Thermoplastics and Thermosets

Plastics can be broadly classified into two types, thermoplastics and thermosets. Both of these are polymers, but have different properties and are used for different applications.

Thermoplastics are plastics that can be melted and reshaped multiple times. They are made up of long, linear molecules that are held together by weak intermolecular forces. When thermoplastics are heated, these forces break down and weak links between the molecules can slide past each other. This allows the plastic to flow and be molded into a new shape. Once the plastic cools, the intermolecular forces reform and the plastic hardens.

Thermosets are plastics that can only be molded once. They are made up of long, cross-linked molecules that are held together by strong covalent bonds. When thermosets are heated, these bonds form and the plastic hardens. Once the plastic has hardened, it cannot be melted or reshaped.

Here are key differences between thermoplastics and thermosets:

Property	Thermoplastics	Thermosets
Melting point	Low	High
Recyclability	Yes	No
Chemical resistance	Good	Poor
Strength	Low	High
Durability	Low	High

Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyvinyl chloride (PVC), Acrylonitrile butadiene styrene (ABS) are some examples of Thermoplastics and Bakelite, Polyester, Polyurethane, Vulcanized rubber are some examples of Thermosets.

Thermoplastics are used in Packaging, Food containers, Toys, Electronics, Medical devices etc. and Thermosets are used in a more limited range of applications, but they are often used in applications where high strength, durability, or chemical resistance is required like Electrical insulation, Adhesives, Composite materials, Gears, Turbine blades etc.

2. PVC (Polyvinyl Chloride)

Polyvinyl chloride (PVC) is the world's third-most widely produced synthetic polymer of plastic (after polyethylene and polypropylene). It was first synthesized in 1872 by German chemist Eugen Baumann after extended investigation and experimentation. In the early 20th century, there were difficulties in processing rigid, and brittle polymer. A method was developed in 1926 to plasticize PVC by blending it with various additives.

PVC is amorphous in nature, and hence it is easily combined with other chemicals/substances. Depending on additives used with PVC, many properties can be modified in products including colour, elasticity, flammability, flexibility, impact resistance, microbial resistance, ageing resistance, resistance to Sun light (UV light) etc..

Polyvinyl Chloride (PVC) is used in manufacturing pipes because of its strength and durability. About 40 million tons of PVC is produced each year. PVC can be manufactured in two forms, rigid and flexible. The rigid form of PVC is used in manufacture of pipe and in applications such as doors and windows. It can be made softer and more flexible by the addition of plasticizers, the

most widely used being phthalates which are esters of Phthalic Acid. The flexible form is used in plumbing, electrical cable insulation, imitation leathers, floorings etc..

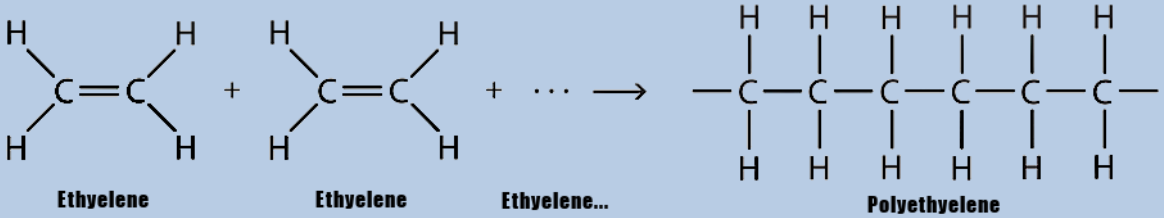
Some major applications of PVC are:

- Roofing and Pipes and fittings
- Power, data and telecoms wiring and cables
- Cable and services ducting
- Internal and external cladding
- ceiling systems and membranes
- Window and door profiles, conservatories other building products
- Rainwater, soil and waste systems
- Flooring
- Wall coverings

3. Polymerization

Polymerization is a process in which small molecules, called monomers, combine to form larger molecules, called polymers. Polymers are made up of repeating units of monomers, and the properties of the polymer depend on the type of monomer used.

a) Polyethylene



In the above image, the reaction of Ethylene to form Polyethylene is indicated. Ethylene is the monomer from which Polyethylene polymer is produced. The double bond in ethylene between two carbon atoms is broken and a new bond is formed between two adjacent carbon atoms in nearby Ethylene molecule.

Polymers are found in many different materials, including plastics, rubber, and textiles. They are also found in living organisms, such as proteins and DNA. Polymerization is a versatile process that is used to create a wide variety of materials with different properties.

4. Polymerization of Polyvinyl Chloride

a) Vinyl Chloride Monomer (VCM)

Polyvinyl chloride (PVC) is manufactured by polymerization of Vinyl Chloride Monomer (VCM). VCM may be manufactured from either naphtha or ethylene dichloride by heating ethylene dichloride in a high temperature furnace or reactor.

$$C_2H_4Cl_2 = C_2H_3Cl + HCl$$

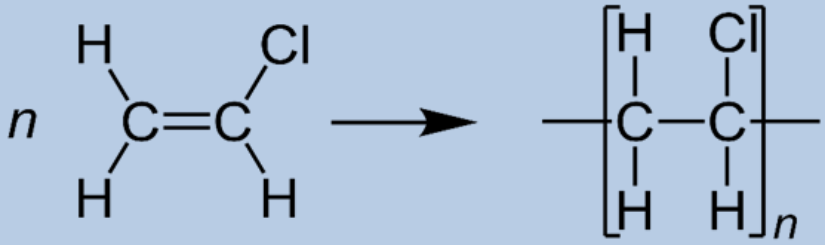
(Ethylene dichloride) = (vinyl chloride monomer) + (hydrogen chloride)

This Vinyl Chloride is used as monomer and polymerized into Polyvinyl Chloride by a process called addition polymerization.

Polymerization of VCM to PVC involves two common methods,

a) **Suspension polymerization** gives particles with average diameters of 100–180µm.
b) **Emulsion polymerization** gives much smaller particles of average size around 0.2µm.

VCM and water are introduced into the reactor along with a polymerization initiator and other additives. Initiators are compounds that generate radicals or cations when subjected to heat or light. These radicals or ions further initiate the bonds causing chain reactions. Hydrogen Peroxide is the common initiator used in PVC polymerization. The contents of the reaction vessel are pressurized and continually mixed to maintain the suspension and ensure a uniform particle size of the PVC resin. The reaction is exothermic and thus requires cooling. As the volume is reduced during the reaction (PVC is denser than VCM), water is continually added to the mixture to maintain the suspension.



5. Properties of Polyvinyl Chloride

a) Electrical Properties: PVC is a good insulation material, thanks to its good dielectric strength.

b) Durability: PVC is resistant to weathering, chemical rotting, corrosion, shock and abrasion. It is therefore the preferred choice for many long-life and outdoor products.

c) Cost to Performance: PVC has good physical as well as mechanical properties & provides excellent cost-performance advantages. It has long life span and need low maintenance.

d) Chemical Resistance: PVC is resistant to all inorganic chemicals. It has very good resistance against diluted acids, diluted alkalis and aliphatic hydrocarbons. However they are prone to react with ketones; some grades are swollen or attacked by chlorinated and aromatic hydrocarbons, esters, some aromatic ethers and amines, and nitro-compounds.

e) Mechanical Properties: PVC is abrasion-resistant, lightweight and tough.

6. Unplasticized-PVC pipes

PVC piping is one of the versatile types of plastic piping. PVC pipes possess good strength and highly durable with very good corrosion resistance properties. It is made softer and more flexible by the addition of plasticizers. If no plasticizers are added, it is known as uPVC (unplasticized polyvinyl chloride).

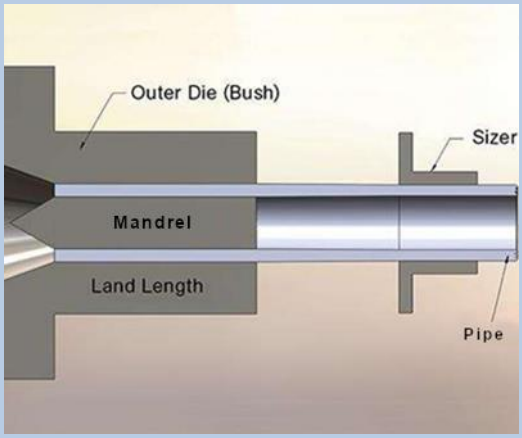
u-PVC pipes are used for potable water supply lines and sewage pipes, irrigation, and water mains. PVC/u-PVC pipes possess very long-lasting properties, they are easy to install, strong, lightweight, durable, and are easily recyclable. The smooth surface of PVC/u-PVC pipes encourages faster water flow due to a low amount of friction as compared to metallic or concrete piping. These pipes can also be manufactured to different lengths, diameters, and wall thickness. Some other typical applications may include Fire Sprinkler Piping, Radiant Floor Heating, Piping inside a Swimming Pool, Chilled Water Systems. Virtually PVC pipes can be used anywhere for transportation of water, or other fluid.



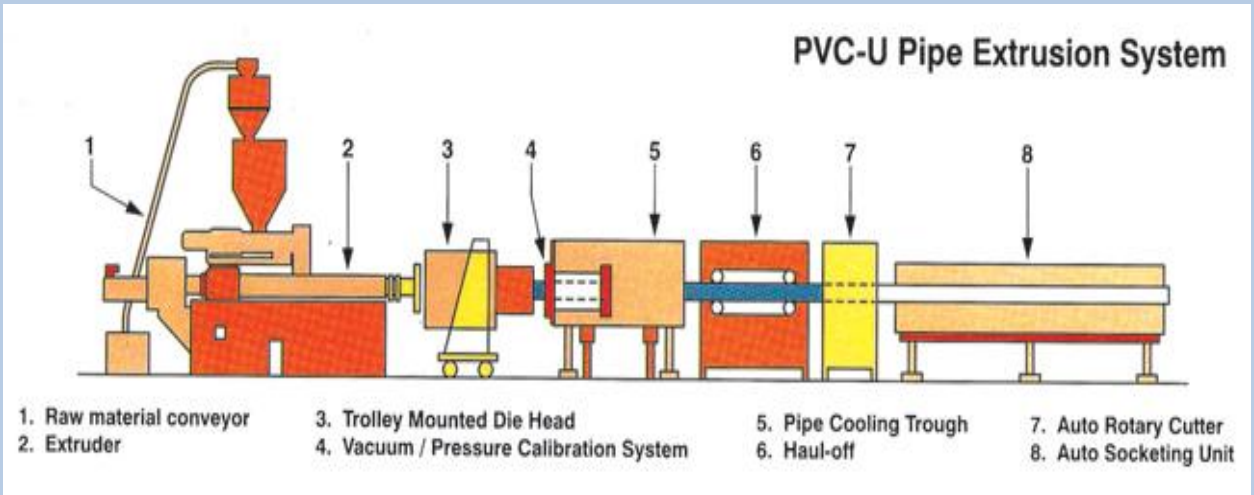


7. Manufacturing of PVC/U-PVC Pipes

PVC/u-PVC pipes are manufactured using a machine called extruder in sizes as small as 20 mm and large as 630 mm. The PVC plastic/resin is fed through a hopper which in turn feeds the extrusion machine at high temperature. Extruder is a screw type system or a conical twin-screw system which pushes the material through a die and mandrel set.



The PVC material takes shape of the cavity through which it flows and a sizer is used to obtain the exact outer diameter of the pipe. The wall thickness of the PVC pipe is determined by gap between the die and mandrel. A vacuum system is also used to avoid flattening or collapse of the pipe while it is still hot and soft. It is then solidified in this shape



in a water-cooling system in the process line. At the end of the assembly line, a ring cutting machine is employed to divide the PVC pipes into sections of individual pipes which are then cooled and racked. The completed PVC pipes are sent to the warehouse for labeling, final inspection, and shipping.

8. Additives in PVC

PVC resin obtained from polymerization is extremely unstable due to its low thermal stability. It needs to be modified before processing into finished products. Its properties can be enhanced/modified by adding several additives, such as heat stabilizers, UV stabilizers, plasticizers, impact modifiers, fillers, flame retardants, pigments, etc. Selection of these additives to enhance polymer's properties is dependent on end application requirement.

a) Plasticizers are used as softening agents to enhance mechanical performance (toughness, strength) of vinyl products by raising the softening temperature.

b) Stabilizer in PVC are necessary as it has very low thermal stability and stabilizers help prevent degradation of polymer during processing or exposure to light. When subjected to heat, vinyl compounds initiate a self-accelerating dehydrochlorination reaction and these stabilizers neutralize the HCl produced enhancing the life of polymer.

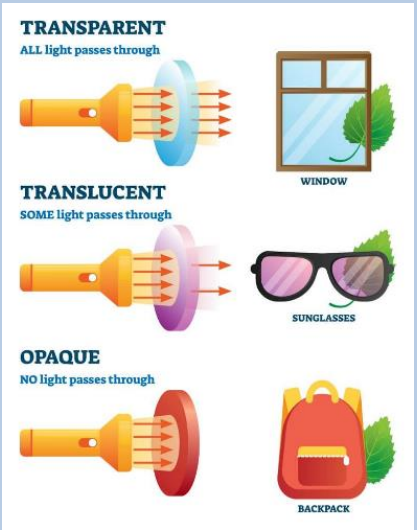
c) Fillers are added in PVC compounds for a variety of reasons. They help to Increase stiffness and strength, improve impact performance, add color, opacity and conductivity. Calcium carbonate, titanium dioxide, calcined clay, glass, talc etc. are common types of fillers used in PVC.

d) External lubricants are used to assist smooth passage of PVC melt through processing equipment, while internal lubricants reduce melt viscosity, prevent overheating and ensure good color of product.

e) Other additives like processing aids, impact modifiers, are added to enhance mechanical as well as surface properties of PVC.

9. Scientific Laws & Quality Requirements

a) **Opacity** - Opacity refers to the measure of how much light is absorbed or blocked by a material. Since, this test is based on the principle of light transmission and absorption, the opacity of a sample is the direct result of absorption and scattering of light including UV rays.



Opacity is tested in PVC Pipes to limit the ingress of light, importantly Ultraviolet light, which is detrimental to the PVC. Ultraviolet light due to its high energy results in breaking bonds/chains of polymers. Pigments and additives have varying abilities to selectively absorb and scatter light.

The PVC pipes shall be made in such a way that not more than 0.2% of light is transmitted through the material for good durability.

b) **Effect on Water** - The plastics contain volatile compounds which slowly evaporate over time. High concentrations of elements like Lead, Cadmium & Mercury can intoxicate the

water. Consumption of the intoxicated water can lead to long term health issues. People with increased sensitivity to heavy metals can suffer reactions. To ensure that the pipes have no detrimental effect on the composition of water, the pipes are to be tested for any toxic substances present. The concentration of toxic substance must not be more than the set values as defined under the relevant Indian Standards.

c) **Reversion Test -** Change in length along the surface of the pipe due to heat and subsequent cooling is called reversion. It is a method of determining the level of internal stresses in pipes. The before and after pictures of the test are shown below,





This test is based on the scientific principle of polymer stability and thermal degradation. During manufacturing of pipe, certain degree of stresses during moulding (residual stresses) and molecular orientations are common. These molecular orientation and stresses get relieved by reheating. Due to high day & night temperature variation in different environmental conditions the pipe undergoes expansion, contraction & stress relaxation process which leads to the change in dimension. The pipe expands and contracts with the rise and fall of the temperature which leads to the failure of assembly particularly joints and water leakage may occur.

d) **Vicat Softening Temperature Test -** The Vicat Softening test is a standard method used to measure the heat resistance and thermal stability of thermoplastic materials like PVC. It determines the temperature at which a defined needle-shaped indenter penetrates the material to a specified depth (1mm) under a specified load (5 kg). As temperature increases, the thermal energy causes the polymer chains in PVC to move more freely, leading to softening and deformation. PVC softens at around 80°C.

Suppose the pipe has to carry water at high temperatures. As we know, that at high temperature, the density of pipe material will decrease. At such condition, the pipe material must remain stable. This is ensured by above test.



e) **Density -** The quantity of mass per unit volume of a substance is known as its density. Density is indirectly an indicator of the compactness or strength of the material. If the density of the pipes is less than the desired minimum value, the mechanical strength will be less. If the density is more than the desired maximum value, the pipes will be heavier. Relative density is the density of any substance relative to the density of reference substance.



Density of an object can be determined by applying the Archimedes principle, which involves weighing of the specimen in air and subsequently in water.

Archimedes Principle: Buoyancy force acting on a body immersed in fluid is equal to the weight of the fluid displaced.

For example, if you were to weigh a rock in air and then weigh it underwater, the underwater weight would be less than the air weight. This is because the rock would displace some of the water, and the buoyant force of the water would push up on the rock, effectively reducing its weight.

The buoyant force is caused by the difference in pressure between the top and bottom of the object. The pressure on the top of the object is equal to the atmospheric pressure, while the pressure on the bottom of the object is greater than the atmospheric pressure because of the weight of the water above it. This pressure difference creates a net upward force on the object.

From this the density of an object can be written as,

$$\text{Density}, \rho = \frac{\text{Wo}}{\text{Wo} - \text{Wi}}$$

Where, Wo is Weight of the object in air

Wi is eight of the object in water

f) **Sulphated Ash Content Test -** The sulphated ash test uses a procedure to measure the amount of residual substance not volatilized from a sample when the sample is ignited in the presence of sulphuric acid. Due to heavy competition, many manufacturers add heavy doses of filler (ex - CaCO3) in PVC products like pipes and profiles, to make them cheaper. To prevent the deterioration of quality of pipe due to addition of filler, this test was introduced, hence, this test helps assess the purity and quality of PVC materials. It helps in providing information about the presence of inorganic impurities or additives that may affect the performance or suitability of the PVC pipes. By measuring the sulphated ash content, manufacturers can ensure that the PVC pipes meet the required standards and have minimal levels of impurities.

g) **Hydrostatic Characteristics Test -** Hydrostatic pressure is defined as "The pressure exerted by a fluid at equilibrium at any point". On PVC pipes we can determine whether a pipe can safely hold the amount of pressure it's rated for. It ensures that the joints are fitted properly and confirms that the material used has the required strength to sustain the pressure. The hydrostatic pressure is generated here through a machine and evaluates the strength and durability of the pipe for a specific period (1 hr or 48hrs). This test is based on the principles of fluid mechanics, including **Pascal's Law**, which states that pressure is transmitted uniformly in all directions in a confined fluid.



10. Interesting facts about PVC

i) PVC is the third most widely produced plastic in the world, after polyethylene (PE) and polypropylene (PP).

ii) PVC is known for its durability and long lifespan. It is resistant to weathering, corrosion, chemicals, and abrasion, making it suitable for both indoor and outdoor applications.

iii) PVC can be rigid or flexible, depending on the additives and plasticizers used during its production. Flexible PVC is commonly used for items such as hoses, cables, and vinyl flooring.

iv) The chlorine content in PVC provides natural flame resistance. It does not support combustion and is self-extinguishing when the source of flame is removed.

v) PVC is resistant to biological growth, making it suitable for applications in water treatment systems, sewage pipes, and irrigation systems.

vi) PVC has a long lifespan and is known for its durability. It can withstand extreme weather conditions, chemicals, and UV radiation, making it ideal for outdoor applications.

vii) PVC has excellent electrical insulation properties, making it suitable for wiring and cable insulation in the electrical industry.

viii) PVC is recyclable. It can be mechanically or chemically recycled to produce new PVC products, reducing waste and environmental impact.

11. Questionnaire

i) What is the primary raw material used in the manufacturing of PVC?
a) Polyethylene
b) Vinyl chloride
c) Acrylonitrile
d) Polypropylene
Answer: b) Vinyl chloride

ii) Which process is commonly used for manufacturing PVC pipes?
a) Extrusion
b) Injection molding
c) Blow molding
d) Compression molding
Answer: a) Extrusion

iii) What is the purpose of adding plasticizers to PVC?
a) To increase the melting point
b) To enhance flame resistance
c) To improve flexibility
d) To reduce density
Answer: c) To improve flexibility

iv) Which property of PVC makes it suitable for electrical insulation?
a) Low thermal conductivity
b) High dielectric strength
c) Excellent corrosion resistance
d) Good UV resistance
Answer: b) High dielectric strength

v) What is the purpose of conducting a hydrostatic pressure test on UPVC pipes?
a) To measure the pipe's weight per unit length
b) To assess the pipe's resistance to thermal expansion
c) To determine the pipe's durability under high pressure
d) To evaluate the pipe's electrical conductivity
Answer: c) To determine the pipe's durability under high pressure

vi) What is the purpose of adding stabilizers to UPVC pipe formulations?
a) To increase the pipe's flexibility
b) To enhance the pipe's color retention
c) To improve the pipe's impact resistance
d) To prevent degradation caused by heat and UV exposure
Answer: d) To prevent degradation caused by heat and UV exposure

Lesson Plan Subjects

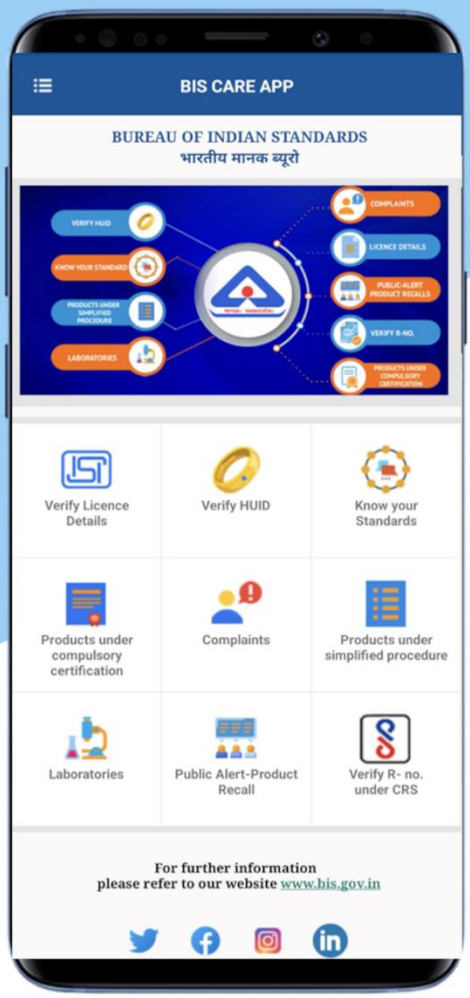
Published

1.	Caustic Soda	**21.**	Ballpoint Pen
2.	Football	**22.**	Bicycle
3.	Cement	**23.**	Electric Iron
4.	Gas Stove	**24.**	Loudspeakers
5.	Geyser	**25.**	Pasteurized Milk
6.	Helmet	**26.**	Paver Blocks
7.	LED Bulb	**27.**	Plugs and Socket
8.	LPG Cylinders	**28.**	Solar Flat Plate Collectors
9.	Cement Ash Brick	**29.**	Precast Concrete
10.	Paints	**30.**	Stainless Steel
11.	Boric Acid	**31.**	Weighing balance
12.	Ceiling Fan	**32.**	Steel Bar
13.	Cables	**33.**	Thermometer
14.	Ceramics Tiles	**34.**	Tyres for buses and trucks
15.	Rear View Mirrors	**35.**	Vacuum Flask
16.	Headphones	**36.**	Water Meter
17.	Milk Powder	**37.**	Wheel Rim
18.	Pressure Cooker	**38.**	Water Storage Tank
19.	Plywood	**39.**	PVC Pipes
20.	Multipurpose dry batteries	**40.**	Refrigerator

Forthcoming…

41.	Drinking Water	**47.**	CNG Cylinders
42.	Electric Mixer	**48.**	Hearing Aids
43.	Family Sized Biogas Plant	**49.**	Microwave Oven
44.	Fire Extinguisher	**50.**	Solid and Hollow Block
45.	Power Threshers	**51.**	Submersible Pump set
46.	Conduits	**52.**	Geosynthetics

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