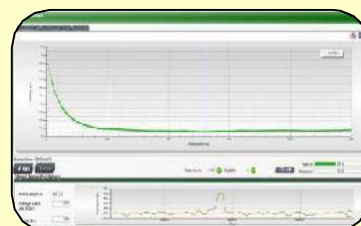
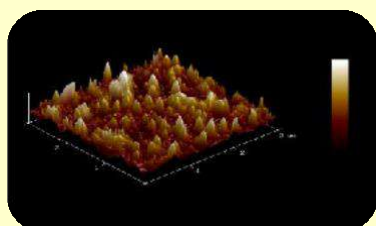
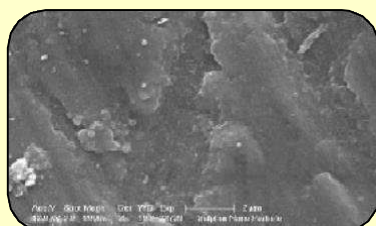


FAQ

Sulphur and its Nano Formulation



ICAR Frequently Asked Questions (FAQ) on Sulphur and its Nano formulation, 2023

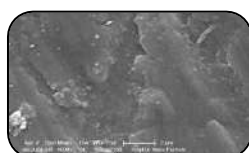
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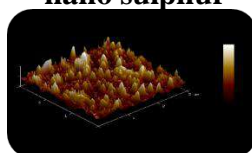
Cover page legend



20% w/v
nano sulphur



SEM image of
nano sulphur



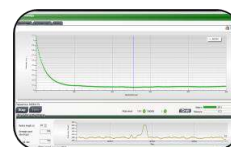
AFM image of
nano sulphur



ICAR-CIRCOT
nano sulphur



Rhombic Sulphur



Particle size graph of
nano sulphur



Monoclinic sulphur

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Abbreviations

Å	Angstrom
AFM	Atomic Force Microscope
CIRCOT	Central Institute for Research on Cotton Technology
cP	Centipoise
CS ₂	Carbon disulphide
DOGR	Directorate of Onion and Garlic Research
ES	Elemental Sulphur
H ₂ S	Hydrogen sulphide
HLB	Hydrophilic-Lipophilic Balance
ICAR	Indian Council of Agricultural Research
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IISS	Indian Institute of Soil Science
MPKV	Mahatma Phule Krishi Vidyapeeth
NIASM	National Institute of Abiotic Stress Management
S	Sulphur
SCU	Sulphur Coated Urea
SEM	Scanning Electron Microscope
SO ₂	Sulphur dioxide
TEM	Transmission Electron Microscopy
WDG	Water Dispersible Granules
XRD	X-Ray Diffraction
XRFS	X-Ray Fluorescence Spectroscopy

General

1. What is sulphur?

Sulphur (S) is the 14th most abundant element in the earth's crust, multivalent and nonmetallic with atomic number 16, and atomic mass 32.06 g/mol. It is crystalline solid at room temperature having a bright yellow colour.

2. What is the position of sulphur in the periodic table?

Sulphur belongs to the oxygen group occurs in group 16, block 'p' and period 3 of the periodic table.

3. What is the electronic configuration of sulphur?

The electronic configuration of sulphur is: $1s^2 2s^2 2p^6 3s^2 3p^4$.

4. What is the origin of the term sulphur?

As per the literature, it could be derived from the word "sufra," or "yellow" in Arabic. Or it could be from the Sanskrit word "Shulbari," which means "enemy of copper."

5. What are the different oxidation states of sulphur?

Sulphur exhibit -2, +2, +4 and +6 oxidation states, and among them +4 and +6 are common oxidation states.

6. What are the different natural sources of sulphur?

Sulphur in the earth's crust occurs as elemental sulphur, sulphide, and sulphate minerals. The sulphate minerals include Anhydrite (CaSO_4), Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), Barite (BaSO_4), Kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$), and Epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), while the sulphide minerals include Pyrites (FeS_2), Chalcocite (Cu_2S), Bornite (Cu_5FeS_4), Digenite (Cu_9S_5), Tetrahydrite ($\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$), Molybdenite (MoS_2), Sphalerite (ZnS), Galena (PbS) etc.

7. What is the abundance of sulphur in nature?

Sulphur is the 14th most abundant element in the earth's crust, 6th most abundant element in seawater, and 11th most abundant element in the human body.

8. What is the odour of sulphur?

Pure sulphur has no smell but when it reacts with hydrogen (H₂), it forms hydrogen sulphide (H₂S) which gives a rotten egg-like smell.

9. What is the use of burning sulphur?

Sulphur after burning turns into sulphur dioxide (SO₂). It is generally burned or vaporized in agricultural fields to control fungus, mites, or insects.

10. What is the colour of the flame when sulphur is burnt?

Sulphur burns with a blue flame with the formation of SO₂ which has a suffocating and irritating odour.

11. What are the physical properties of sulphur?

The physical properties of sulphur are as follows:

Properties	Characteristic
Colour	Pale yellow - Non-metallic
Phase	Solid
Crystalline structure and forms	Rhombic, Amorphous and Prismatic
Melting point	111 to 115°C
Boiling point	444.6°C
Atomic number	16
Atomic mass	32.06 g/mol
Mohs hardness	1.5 to 2.5
Specific gravity	2.0 to 2.1
Odour	Odourless
Taste	Tasteless
Conductivity	Poor conductor of heat and electricity
Density	2.07 g/cm ³ at 20°C
Block in the periodic table	p
Viscosity	Upon melting, sulphur is converted into a mobile yellow liquid, which turns brown and becomes a viscous, dark brown mass at about 190°C. The viscosity decreases above 190°C, and at 300°C sulphur again becomes a flowing liquid

12. What happens when sulphur is heated?

When sulphur is heated, it starts melting at 115°C, then there is a change in colour from yellow to red at 200°C, and it starts to boil at 400°C. Before reaching the boiling point, it starts to vaporize. When it is heated above 445°C, ignition takes place.

13. What is the length of the sulphur-sulphur single bond?

The length of the sulphur-sulphur single bond is generally about 2.1 Å (2.1×10^{-10} m).

14. What is the shape of sulphur (S₈) molecule and its bond angle?

The sulphur (S₈) molecule has puckered ring structure and the bond angle is 107.8°.

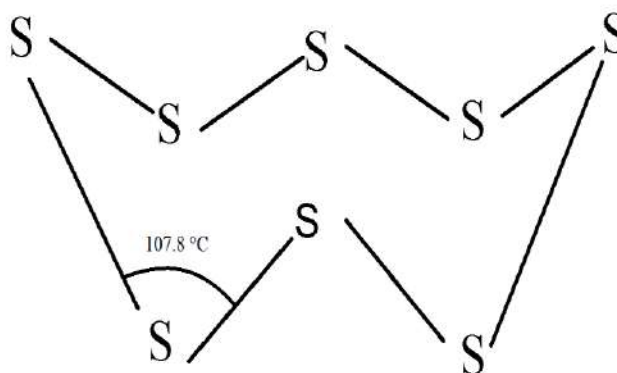


Figure 1: Puckered ring structure of sulphur

15. What are the four stable isotopes of sulphur?

Sulphur has four stable isotopes: ³²S (95.02%), ³³S (0.75%), ³⁴S (4.21%), and ³⁶S (0.02%).

16. Which property allows sulphur to form ring systems and chain structures in sulphur atoms?

Catenation allows sulphur to form ring systems and chain structures in sulphur atoms. Catenation is the property by which the self-linking of atoms of an element through a covalent bond takes place to form straight chains, branched chains, and cyclic chains of different sizes.

17. Which metals do not combine with sulphur to form inorganic sulphides?

Gold and platinum are two metals that do not combine with sulphur to form inorganic sulphides.

18. Why sulphur shows the property of allotropy?

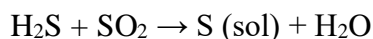
Sulphur shows the property of allotropy because of the different modes of bonding of atoms into a single molecule and the packing of polyatomic sulphur molecules into different crystalline and amorphous forms.

19. What are sulphur sols?

Sulphur sols are colloidal solutions of elemental sulphur or sulphur-rich compounds, is a type of multi-molecular colloid. The particles in these solutions have diameters of 0.1–1.0 μm and consist either of S_8 molecules (hydrophobic sulphur sols) or of chain-like sulphur compounds with hydrophilic end groups like sulphonate or functionalized organic groups (hydrophilic sulphur sols).

20. How is sulphur sol prepared?

A sulphur sol can be prepared by passing hydrogen sulphide (H_2S) into the solution of sulphur dioxide (SO_2) in water. The reaction is as follows:



21. What is the viscosity of liquid sulphur?

The viscosity of sulphur in liquid form is in the range of 7-10 cP at a temperature ranging from 130°C to 145°C.

22. What is the relationship between temperature and viscosity of sulphur?

The viscosity of sulphur increases gradually at a lower temperature. However, at a temperature higher than 155°C, the viscosity increases asymptotically. At λ -transition ($T > 160^\circ\text{C}$), molten sulphur undergoes polymerization which leads to a sharp increase in its viscosity from 70 cP (160°C) to a maximum of 930000 cP (187°C).

23. Why is sulphur characterized as non-metal?

Sulphur is characterized as a non-metal because of the following physical and chemical properties:

Physical	Chemical
Poor Conductor of heat and electricity	High electronegativity
Dull and brittle in solid form	Negative valency
Lower densities than metals	

24. What is the most abundant form of sulphur found in nature?

Sulphur is widely found in nature as iron pyrite (iron sulphide, FeS), Galena (lead sulphide, PbS), Gypsum (calcium sulphate, CaSO₄.2H₂O), Chalcocite (copper sulphide, Cu₂S), and Sphalerite (zinc sulphide, ZnS), Epsom Salts (magnesium sulphate, MgSO₄) and in many other minerals.

25. Which form of sulphur shows paramagnetic behaviour and why?

Sulphur in the vapour phase exists as S₂ (disulphur) molecule that shows paramagnetic behaviour because S₂ has two unpaired electrons in its anti-bonding pi molecular orbitals.

26. How many allotropes of sulphur exist?

There are mainly 8 allotropes of sulphur out of which five contain rings of sulphur atoms and the others contain chains.

27. What are the reducing agents based on sulphur?

Some of the sulphur based reducing agents are: Sodium sulphide (Na₂S), Hydrazine sulphate (N₂H₆SO₄), Sodium thiosulphate (Na₂S₂O₃), Ammonium thiosulphate ((NH₄)₂S₂O₃), Sodium dithionite (Na₂S₂O₄), and Thiourea oxide (CH₄N₂O₂S).

28. What is Glauber's salt?

Glauber's salt is the decahydrate form of sodium sulphate Na₂SO₄.10H₂O. It is naturally present in saline areas like saline playa lakes and saline springs.

29. What is the use of Glauber's salt in agriculture?

Glauber's salt is used as a fertilizer in agriculture. It enhances the development of crops and also helps in increasing yield.

30. What are the strongest peaks of elemental sulphur in XRD?

Sulphur can be easily identified using diffraction patterns. The strongest peaks (2θ) of sulphur with d value are: 22.77 (3.90), 27.38 (3.25), and 25.48 (3.49)

31. What are the three main allotropic forms of sulphur?

Three main allotropic forms of sulphur are:

- i) Rhombic sulphur or α -sulphur
- ii) Monoclinic sulphur or β -sulphur
- iii) Plastic sulphur or γ -sulphur

32. Which form of sulphur is most stable at room temperature?

Rhombic sulphur is the most stable form of sulphur at room temperature.

33. What is rhombic sulphur?

It is an allotropic form of sulphur consisting of pale yellow crystals. One molecule of rhombic sulphur contains 8 atoms (octahedral structure) and is stable below 96°C. It is stable at room temperature and melts at 110°C. It is insoluble in water and soluble in carbon disulphide.

34. How is rhombic sulphur prepared?

Rhombic sulphur is prepared by dissolving ordinary powdered sulphur in carbon disulphide (CS_2). The saturated solution is then filtered and the filtrate is allowed to evaporate at room temperature. After slow evaporation of CS_2 , large octahedral crystals of rhombic sulphur are obtained.



Figure 2: Rhombic sulphur and Monoclinic sulphur

35. What is monoclinic sulphur?

It is the allotropic form of sulphur consists of 8 sulphur atoms, however the arrangement of atoms is different from that of rhombic sulphur. This form is stable between 96 to 119°C. It is soluble in carbon disulphide.

36. How is monoclinic sulphur prepared?

It is prepared by taking ordinary sulphur which is mullied in a china dish with slow heating. The molten sulphur is allowed to cool down until a crust is formed at the surface, the holes are made in the crust by glam rod and molten sulphur is powered out, the crust is also removed and at the bottom, needle shaped crystals of monoclinic sulphur are left.

37. What is γ -sulphur?

γ -sulphur also known as nacreous sulphur, crystallizes in pale yellow monoclinic needles. It is the densest of all 3 forms of sulphur. It can be prepared by slowly cooling molten sulphur that has been heated above 150°C.



Figure 3: γ -sulphur

38. What is the transition temperature for sulphur?

The transition temperature is the temperature at which both the allotropes (α and β) of sulphur are stable. The value of transition temperature for sulphur is 95.85°C.

39. Which allotropic form of sulphur has elastic property?

γ -sulphur, also known as plastic sulphur has an elastic property.

40. What is the size of commercially available elemental sulphur powder?

The size of commercially available sulphur is approximately 100-200 mesh (150 to 75 microns).

41. Why is it necessary to remove sulphur from petroleum products? How is it harmful?

It is necessary to remove sulphur from petroleum products to reduce the emission of sulphur dioxide (SO_2) from the exhaust. Sulphur dioxide damages vegetation by causing chlorosis. In human beings, it causes irritation in the eyes and damages the respiratory system. It also causes acid rain by forming sulphurous acid (H_2SO_3) and sulphuric acid (H_2SO_4) damaging buildings and plants.

42. Why does sulphur burn with a blue flame?

Sulphur burns with a blue flame because of the excitation of the electrons to a higher energy state. While coming to the ground state, they relax and emit energy in the blue-violet end of the visible spectrum.

43. What are the major sources of emission of sulphur dioxide in the atmosphere?

The major source of emission of sulphur dioxide in the atmosphere is the burning of fossil fuels such as coal, petroleum and natural gases by power plants, vehicles and other industrial facilities.

44. Which is the largest source of elemental sulphur?

The largest source of elemental sulphur is the petroleum and natural gas industry and is produced as a byproduct upon removal of sulphur-containing contaminants from petroleum and natural gas.

45. What are sulphur dyes?

Sulphur dyes are the most commonly used dyes for cotton textile. Sulphur dyes are manufactured by melting or boiling natural or synthetic organic compounds containing amino or nitro groups with sodium-polysulphide and sulphur.

46. What is sulphur cycle?

The sulphur cycle is a biogeochemical cycle consisting of various processes that enable the movement of sulphur through different reservoirs like atmosphere, biosphere and lithosphere. The important steps in sulphur cycle are:

A. Decomposition of organic compounds

- Protein degradation by the action of *Desulfotomaculum spp.* bacteria releases H₂S from amino acids.
- B. Oxidation of hydrogen sulphide to elemental sulphur
- Certain photosynthetic bacteria from the families Chlorobiaceae and Chromatiaceae initiate the oxidation process.
- C. Oxidation of elemental sulphur
- Elemental sulphur present in the soil cannot be utilized directly by the plants. It is converted into sulphates by chemolithotrophic bacteria like *Thiobacillus spp.*
- D. Assimilatory sulphate reduction
- Plants and microorganisms produce cysteine from sulphates by assimilatory sulphate reduction process and store in proteins.
- E. Dissimilatory sulphate reduction
- Some types of bacteria and archaea produces sulphides from sulphates by dissimilatory sulphate reduction and release into the environment.

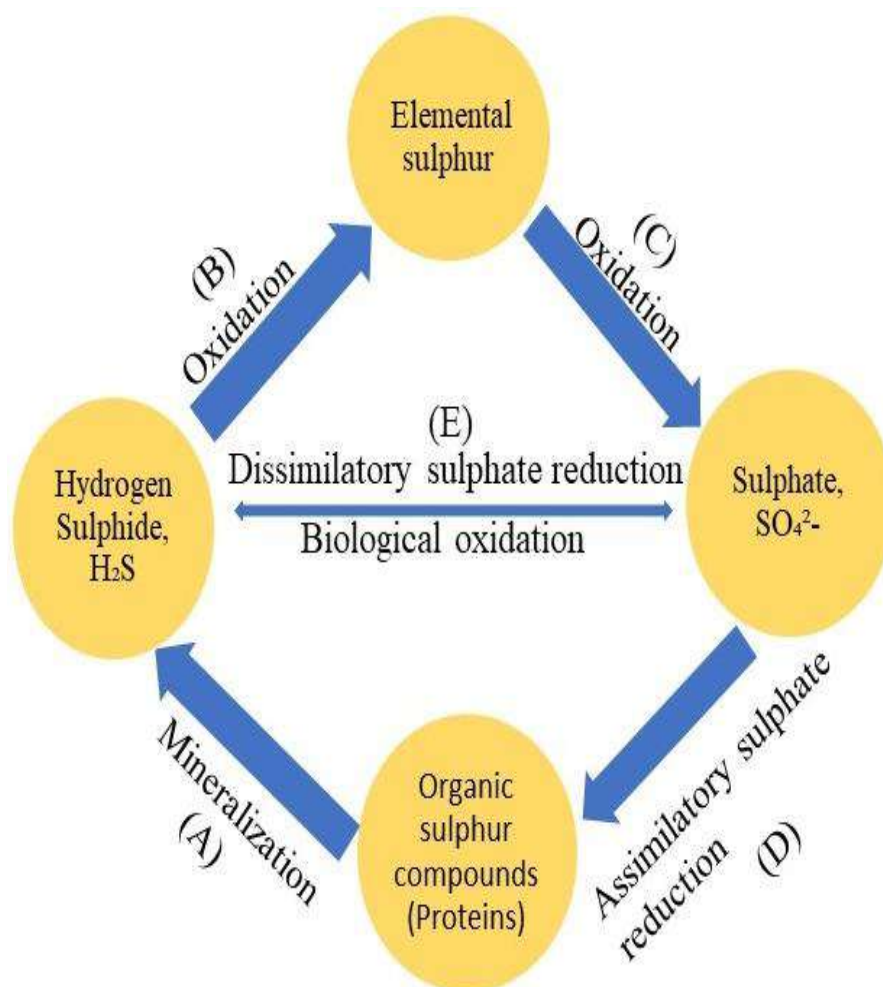


Figure 4: The sulphur cycle

47. What is the solubility of sulphur in different solvents?

Solvent	Percentage
Water	Insoluble
Ethanol	0.066
Acetone	0.079
Diethyl ether	0.181
Dimethylformamide	0.191
n-Hexane	0.40
Carbon tetrachloride	0.832
Nitrobenzene	0.856
Chloroform	1.164
Cyclohexane	1.185
Aniline	1.259
Xylene	2.051
Toluene	2.070
Benzene	2.093
Chlorobenzene	2.370
Carbon disulphide	34.80

(Source: <https://www.researchgate.net/post/In-which-organic-solvent-is-suitable-for-sulfur>)

Application of sulphur in agriculture

48. What are the macronutrients required for a plant system?

Nitrogen (N), phosphorus (P), potassium (K), and sulphur (S) are the most important macronutrients required for a plant system.

49. What is the role of sulphur in nitrogen fixations in plants?

Sulphur plays a very important role in nitrogen-fixation in plants through an enzyme called nitrogenase, which contains sulphur. Nitrogenase is an enzyme that converts atmospheric nitrogen to ammonia.

50. How much sulphur do plants need?

On average, most crops require 15 to 30 kg of sulphur per hectare. Some of the crops such as oilseeds, legumes, forages, and some vegetables such as onion, and garlic require more sulphur for optimal yield and quality.

51. What are the disadvantages of direct application of water-soluble sulphate fertilizers?

The disadvantages of direct application of water-soluble sulphate fertilizers like ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$ are:

- 1) Uncontrolled release of fertilizer
- 2) Leaching during incessant precipitation
- 3) Over dissolution of fertilizers leads to groundwater pollution

52. When a plant is said to be severely deficient in sulphur?

A plant is said to be severely deficient in sulphur if its leaves contain less than 0.15% of sulphur on a dry matter basis.

53. List a few sulphur responsive crops?

Some of the sulphur responsive crops are onion, garlic, chillies and oilseeds such as canola, mustard, soybean, sunflower, groundnut, etc.

54. Which crops are most sensitive to sulphur fertilization?

Crops such as gooseberries, apricots, raspberries, cucurbits family (cucumbers, squash, melons) and peaches are most sensitive to sulphur fertilization.

55. What is the prime role of sulphur in plant growth and development?

Sulphur plays a very important role in plant growth and development as it helps in:

- 1) Formation of chlorophyll that permits photosynthesis.
- 2) Protein production as amino acids such as cysteine, cystine and methionine contains sulphur.
- 3) Synthesis of oil in oilseed crops.
- 4) Activation of enzymes.
- 5) Increasing the crop yield and improving product quality.
- 6) Improving the cereal quality for milling and baking.

56. What is the average size of stomata in plants?

The average size of stomata varies across species but on an average, the end-to-end lengths range from 10 to 80 μm and the width ranges from a few to 50 μm .

57. How many sulphur forms can be absorbed by the plants?

Plants can absorb three forms of sulphur i.e. sulphate (SO_4^{2-}), thiosulphate ($\text{S}_2\text{O}_3^{2-}$) and sulphur dioxide (SO_2).

58. What are the symptoms of sulphur deficiency in plants?

The symptoms of sulphur deficiency first appear on the younger leaves indicated by turning of leaves to pale-yellow or light-green and red pigmentation of leaf margins and petiole.

59. What is sulphur coated urea (SCU)?

Sulphur coated urea (SCU) is a slow-release fertilizer that is made by coating urea with sulphur and paraffin wax that increases nitrogen efficiency, improves plant growth and reduces water pollution, compared with water-soluble fast-release urea.

60. What are the different forms of sulphur commercially available for agricultural application?

Elemental sulphur, lumps, granules, bentonite sulphur and water dispersible granules (WDG) are different commercially available forms of sulphur for agricultural application.

61. What is the present status of sulphur deficiency in Indian soils?

About 25% of the 30,578,612 soils analyzed in India during 2021-2022 had a deficiency of sulphur. Soils containing less than 10 ppm sulphur are considered to be low or deficient in plant available sulphur

(Source: Ministry of Agriculture and Farmers Welfare, Government of India).

<https://www.soilhealth.dac.gov.in/NewHomePage/StateWiseNPKChart>

62. What are the commercially available fertilizers containing sulphur?

Nutrient	Fertilizers
Nitrogen	Ammonium sulphate ((NH ₄) ₂ SO ₄), Ammonium phosphate sulphate ((NH ₄) ₂ (H ₂ PO ₄)(HSO ₄))
Phosphorus	Single superphosphate, Rock phosphate
Potassium	Potassium sulphate (K ₂ SO ₄), Potassium magnesium sulphate (K ₂ Mg ₂ O ₁₂ S ₃)
Micronutrient	Zinc sulphate (ZnSO ₄), Copper sulphate (CuSO ₄), Manganese sulphate (MgSO ₄)

63. What is the subsidy given for sulphur fertilizer by the government of India?

The subsidy for sulphur containing fertilizers is ₹6.12/kg for the year 2022.

(Source: Government of India Department of Fertilizers No. 23011/12/2022-P&K dated 02/11/2022)

64. What is the average sulphur uptake for oilseed, pulses and cereal crops?

The average sulphur uptake (in kg per metric ton of grain) by crops is reported to be 9.9 for oilseeds, 7.6 for pulses or beans and 4.1 for cereals, respectively.

65. What is the market size of sulphur fertilizers?

The market size of sulphur fertilizers is estimated to reach \$5.1 billion by 2025 with an annual average growth of 2.2% during 2020-25. The increase in sulphur deficiency in soil, intensive agricultural practices, use of improved crop varieties and rise in area under irrigation are the factors that will increase the market demand for sulphur fertilizers during the period.

(Source: <https://www.marketsandmarkets.com/PressReleases/sulfur-fertilizer.asp>)

66. How does sulphur fertilizer improve crop quality?

Sulphur improves crop quality by:

- Increasing the oil content of seeds.
- Increasing protein percentage in plants and harvested produce.
- Improving the nutritional quality of forages by providing a balanced N: S ratio.
- Improving starch content of tubers.
- Improving the baking quality of wheat.
- Increasing sugar recovery in sugarcane.
- Enhancing marketability of copra (coconut kernel).

67. In which form sulphur is present in plant tissues?

Sulphur is present as SH⁻ (thiol or sulphhydryl group), sulphide and sulphate forms in plant tissues.

68. How does elemental sulphur lower the soil pH?

Elemental sulphur when added to soil goes through a transformation process called oxidation with the help of *Thiobacillus thiooxidans* bacterium, converting elemental sulphur into sulphuric acid (H₂SO₄), which lowers the soil pH.

69. What is the percentage of organic and inorganic sulphur present in the soil?

The majority of sulphur i.e., more than 95% present in the soil is organic form. On the other hand, inorganic sulphur makes up only less than 5% of the total sulphur present in the soil.

70. Which is the sulphur containing vitamin synthesized by the plants?

Thiamine or Vitamin B₁ is the vitamin synthesized in plants containing sulphur.

71. What are the factors responsible for sulphur deficiency in soils?

Several factors contribute to the sulphur deficiency in soils such as:

- Increased agricultural production results in loss of sulphur (and other nutrients).
- Agronomic practices increased net depletion of soil sulphur.
- Low level of sulphur fertilizer used in pulses and oilseeds cultivation that have a higher requirement of sulphur.
- Sulphur losses through leaching and runoff.
- Use of sulphur-free fertilizers such as urea, diammonium phosphate (DAP), muriate of potash (MOP), etc.

72. How is the sulphur being transported in the plant system from soil?

Sulphur in sulphate form (SO_4^{2-}) is actively taken up across the plasma membrane of the root cells from soil. It is subsequently loaded into the xylem vessels and transported to the shoot by the transpiration stream. The uptake and transport of sulphate is energy dependent through a proton/sulfate co-transport.

73. What is the role of sulphur in organic farming and home gardening?

Sulphur is used as a fungicide and acaricide to control mites and ticks in organic farming and in home gardening other than providing nutrients to plants.

74. How does the foliar uptake of sulphur dioxide (SO_2) take place by the plants?

The foliar uptake of sulphur dioxide (SO_2) takes place through the stomatal opening present on the leaves and directly depends on the degree of opening of the stomata.

75. What are the factors affecting the availability of sulphur to the plant through the soil?

Factors affecting the availability of sulphur to the plant through soil depend upon:

- a) Available sulphur in the soil
- b) Microbial activity
- c) Soil pH (optimum pH 6.0 to 7.5)
- d) Soil temperature (Optimum 30 to 40°C)

76. What are the average application rate and crop response to the sulphur application?

Average crop responses to a sulphur application under field conditions are as follows:

Crop	Mean application rate, (kg/ha)	Increase in yield kg grain/kg S
Wheat	39	19
Rice (Paddy)	42	16.6
Chickpea	85	5.3
Pigeon pea	36	8.9
Black gram	30	5.4
Green gram	40	3.3
Groundnut	34	13.3 (pods)
Mustard	43	7.7
Sunflower	24	13
Soybean	36	9.4
Linseed	26	9.5

(Source:<https://www.sulphurinstitute.org/about-sulphur/sulphur-the-fourth-major-plant-nutrient/sulphur-fertilizer-crop-yield>)

77. What are the different methods for the determination of elemental sulphur?

Free elemental sulphur can be determined by converting it into copper (I) sulphide at 150–170°C. The copper (I) sulphide can be weighed, or its sulphur content determined by the iodimetric method. Other instrumental techniques for sulphur estimation in ppm level are XRFS and ICP/MS.

78. What are the different analytical methods to determine sulphur content in soil?

Different analytical methods to determine sulphur contents in soils are:

- a) Determination of total sulphur in soils and plants by an automated dry combustion method
- b) An alkaline oxidation method for determination of total sulphur in soils (M. A. Tabatabai and J. M. Bremne, 1970)

- c) Determination of total sulphur in soil and plant material (Steinbergs, A, O, Iismaa, J. R. Frency and N. J. Barrow, 1962)
- d) An X-ray spectrographic method of determining total sulphur in soil extracts (Roberts S and F. E. Koehler, 1964)
- e) Determination of available sulphur in soils by 0.15 % CaCl₂ solution (Chesnin, L., & Yien, C. H., 1950)

79. What are the different analytical methods to determine sulphur content in plants?

The different analytical methods to determine sulphur content in plants are:

- a) Determination of total sulphur in soils and plants by an automated dry combustion method.
- b) Determination of total sulphur in soil and plant material (Steinbergs, A, O, Iismaa, J. R. Frency and N. J. Barrow, 1962)
- c) A simple turbidimetric method of determining total sulphur in plant materials (M. A. Tabatabai and J. M. Bremner, 1970)
- d) Determination of total sulphur in the plant by diacid method.

80. What is the interaction of sulphur with other nutrients present in the soil?

The interaction of sulphur with other nutrients present in the soil is as follows:

- a) Sulphur and Iron (Fe): Low level of S exhibited low iron uptake
- b) Sulphur and Manganese (Mn): Application of S fertilizer to the soil will enhance Mn uptake by the plants
- c) Sulphur and Copper (Cu): Antagonistic relationship between S and Zn is observed
- d) Sulphur and Boron (B): Positive interaction between B and S
- e) Sulphur and Molybdenum (Mo): Antagonistic relationship between S and Mo is observed
- f) Sulphur and Chlorine (Cl): Mutual antagonistic relationship

81. What is meant by green synthesis of nano sulphur?

Green synthesis of nano sulphur is a process for synthesizing sulphur nanoparticles using biological routes such as those involving microorganisms, plants, and viruses or their by-products, such as proteins and lipids.

82. What are the merits of using green synthesis for synthesizing nano sulphur?

The merits of using green synthesis for synthesizing nano sulphur are sustainability, safety, affordability, quick synthesis and simple protocols.

83. Why green synthesis is preferred over other methods for synthesizing nano sulphur particles?

Green synthesis is preferred over other methods for synthesizing nano sulphur because it is a cost-effective, eco-friendly method as the biological component itself acts as a reducing and capping agent, and external experimental conditions like high energy and high pressure are not required leading to an energy-saving process.

84. What are the different plant species from which nano sulphur can be synthesized by green synthesis?

Some of the plants like banyan leaves, pomegranate, basil, garlic, rosemary, etc. are utilized to synthesize nano sulphur. (Source: Ghotekar et al. 2020)

85. What is the sulphur content of pig and cattle manure?

The sulphur content of pig and cattle manures is 0.9-1.2 kg/tonne (~0.1%).

86. What is purple sulphur bacteria?

The purple sulphur bacteria (PSB) are part of a group of proteobacteria capable of doing photosynthesis. They are anaerobic and can use sulphide or thiosulphate as an electron donor in the photosynthetic pathway.

87. What is green sulphur bacteria?

Green sulphur bacteria are strict anaerobes that are capable of photosynthesis. They use reduced sulphur compounds as their electron donors and fix carbon using the reverse TCA (tricarboxylic acid) cycle. These bacteria live in sulphur-rich environments that have characteristically low light intensities.

88. What is the cost of elemental sulphur in the Indian market?

The approximate cost of elemental sulphur in lump form is ₹15-20/kg and in powdered form is ₹20-30/ kg.

89. What is bentonite sulphur?

Bentonite sulphur is a sulphur-based fertilizer that contains 90% sulphur and 10% bentonite clay which serves as a binder during manufacture and as a dispersing agent after addition to soils.

90. List the major manufacturers of bentonite sulphur in India?

- Coromandel International Limited
- Deepak Fertilizers and Petrochemicals Corporation Limited, Taloja (Maharashtra)
- National Fertilizers Limited, Noida (Uttar Pradesh)
- Prathista Industries Limited, Hyderabad (Telangana)
- Kiran Chemicals, Lucknow (Uttar Pradesh)
- IFFCO, New Delhi

91. What is the cost of bentonite sulphur in the Indian market?

The cost of bentonite sulphur in the Indian market is ₹25-100/kg.

92. What is the cost of Water Dispersible Granules (WDG) sulphur in the Indian market?

The cost of Water Dispersible Granules (WDG) sulphur in the Indian market is ₹70-100/kg.



Figure 5 (a): Bentonite sulphur



Figure 5 (b): WDG sulphur

Synthesis of nano sulphur

93. Which are the nano-technological approaches that can be used for synthesis of nano sulphur?

There are two approaches used for the synthesis of nano sulphur: the top-down (mechanical) approach and the bottom-up (chemical) approach.

94. What is the top-down approach for the synthesis of nanoparticles?

The top-down approach is a method of nanofabrication that involves the breaking down of bulk material into nanosized structures or particles using mechanical methods.

95. What is the bottom-up approach for the synthesis of nanoparticles?

The bottom-up approach is a method of nanofabrication that makes the use of chemical or physical forces operating at the nanoscale to assemble basic units like atoms or molecules into nanoparticles.

96. Which is the most common precursor used for nano sulphur preparation?

Sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) is the most common precursor used for nano sulphur preparation in bottom-up approach.

97. What are the different surfactants used during the chemical synthesis of nano sulphur?

Cetyl Trimethyl Ammonium Bromide (CTAB), Sodium Lauryl Sulphate (SLS), Tween 80, etc. are the different surfactants used during the chemical synthesis of nano sulphur.

98. What is the Hydrophilic-Lipophilic Balance (HLB) of a surfactant?

Hydrophilic-Lipophilic Balance (HLB) of a surfactant is a measure of the degree to which a surfactant is hydrophilic or lipophilic. The HLB scale ranges from 0 to 20. An HLB value of 0 corresponds to a completely lipophilic/hydrophobic molecule, and a value of 20 corresponds to a completely hydrophilic/lipophobic molecule.

99. What are the different types of surfactants that can be used in bottom-up synthesis of nanoparticles?

There are four different types of surfactants: anionic, cationic, nonionic and amphoteric.

100. What is the role of surfactant in the synthesis of nano sulphur?

Surfactant plays a very important role in the synthesis of nano sulphur. Sulphur is immiscible with water. A suitable surfactant helps in forming a slurry of sulphur with water which also prevents the quick agglomeration of sulphur particles.

101. What is the colour of nano sulphur powder?

Sulphur nano powder is generally light yellow in colour.

102. What is the colour of nano sulphur dispersed in the aqueous medium?

Nano sulphur dispersed in aqueous medium is milky white.

103. What is the cost of commercially available nano sulphur powder in the Indian market?

The cost of commercially available nano-sulphur powder in the Indian market is approximately ₹1800-2000 for 10 g.



Figure 6: Nano sulphur dispersed in aqueous medium

Development of nano sulphur at ICAR-CIRCOT

104. What are the different equipment available with ICAR-CIRCOT that could be used for the synthesis of nanomaterials?

Super mass colloidar, High-pressure homogenizer (working pressure: 2500 kg/cm²), and Vibrating ball mill are the different mechanical equipment's that are being used for the synthesis of nanomaterials.

105. What are the different instruments used to characterize nano sulphur?

Particle size analyzer, Viscometer, Goniometer, Zeta potential analyzer, Scanning electron microscope (SEM), X-ray diffraction (XRD), Diffused Reflectance Infra-red Fourier transform technique (DRIFT-IR), BET surface area, and RAMAN spectroscopy are the different instruments used to characterize nano sulphur.

106. What inferences can be made through the micrograph of elemental and nano sulphur using SEM and TEM?

The SEM analysis of the elemental sulphur sample revealed a wide distribution of the particle size ranging from 8-45 microns. However, the TEM analysis of the mass colloidar sample corroborated the size reduction in the range of 300-500 nm. The representative images are shown in the figure 7 below:

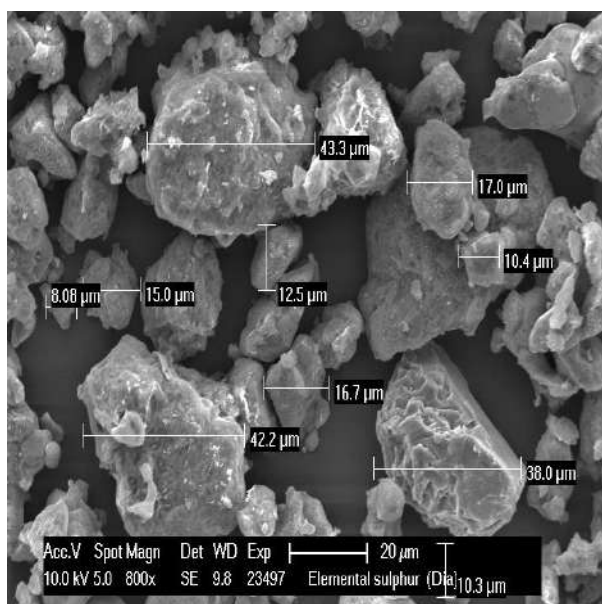


Figure 7(a): SEM image of elemental sulphur

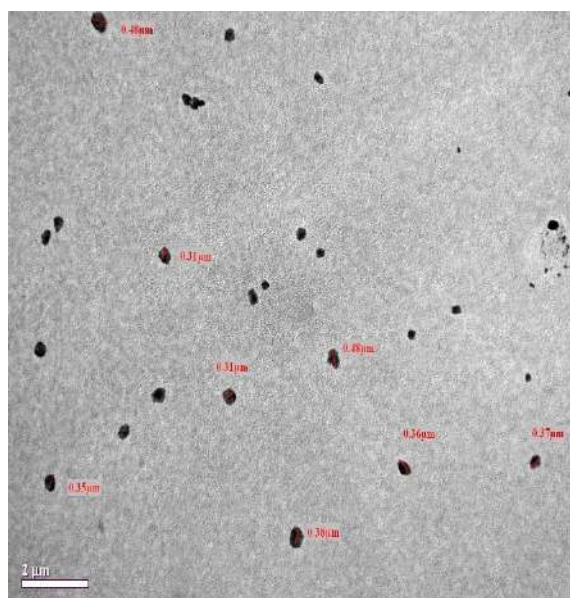


Figure 7(b): TEM image of ICAR-CIRCOT nano sulphur

107. Which institutes are involved in field trial of nano sulphur developed by ICAR-CIRCOT?

ICAR-CIRCOT has initiated an inter-institutional project for conducting the field trials of nano sulphur with different institutes and state agricultural universities viz. (i) ICAR-Indian Institute of Soil science (IISS) Bhopal, (ii) ICAR-Directorate of Onion and Garlic (DOGR), Rajgurunagar, (iii) ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati, and (iv) Mahatma Phule Krishi Vidhyapeeth (MPKV), Rahuri.

108. What are the ways through which nano sulphur can be applied to plants?

Nano sulphur can be applied to plants in the form of basal dose. The total sulphur required by the crop during the season may be distributed according to the requirement at different growth stages. The nano sulphur dispersion can be applied by diluting with adequate water. The formulation may then be applied to the crop using a sprayer or through fertigation.

109. What are the pros and cons regarding the development of nano sulphur?

The bottom-up approach for the synthesis of nanoparticles is associated with a few shortcomings like less yield, effluent generation, time consuming etc. Therefore, to overcome these limitations, top-down approaches are adopted with added advantages of higher yield, efficiency, economical with less effluent generation. The involvement of sophisticated size reduction equipment's may add additional capital and energy to the overall process.

110. Whether any patent has been filed by ICAR-CIRCOT on nano sulphur?

The institute has filed a patent application entitled, 'Novel chemo-mechanical method for preparation of nano sulphur' having application number 202221013740 and submitted on 14th March, 2022.

111. What is the ICAR-CIRCOT process protocol for the synthesis of nano sulphur?

The most common form of sulphur available is elemental sulphur (ES) mostly obtained as a major by-product of the petroleum refining and natural gas purification processes therefore efforts were made to utilize ES as the raw material for the synthesis of nano

sulphur. Optimized concentration of a suitable surfactant was used for stabilization of the suspension. The ES sample was diluted with an adequate amount of water and stirred at a particular speed for a specific duration. The obtained sample was subjected to grinding in a mass colloidar till the particles in the suspension reached the desired size of 400-500 nm. The process protocol is presented in the following flow diagram:

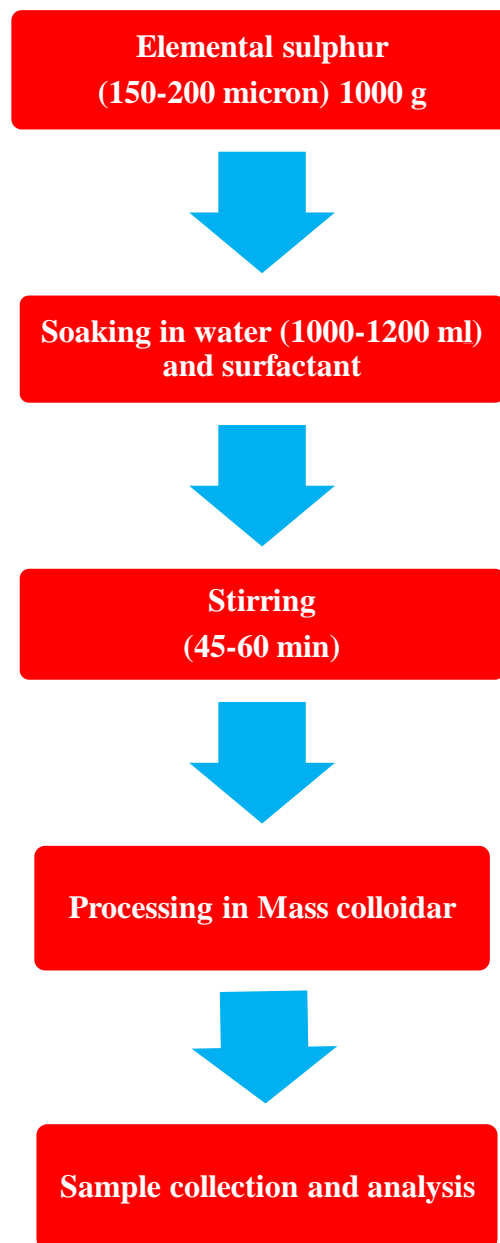


Figure 8: Process protocol for the synthesis of nano sulphur using chemo-mechanical approach

112. Which are the countries working on the synthesis of nano sulphur?

The literature review suggests that the researchers from the countries like India, South Korea, United States of America, and China are involved in the research related to the synthesis, and application of nano sulphur.

113. What are the different instrumental facilities available with ICAR-CIRCOT that could be used for the synthesis of nanomaterials?

Super mass colloidier, High-pressure homogenizer (working pressure: 2500 kg/cm²), and Vibrating ball mill are the different mechanical equipment's that can be used for the synthesis of nano materials.

114. What is the patent status regarding nano sulphur in India and in other countries?

S. No.	Countries	No. of Patents	Title
1	India	2	A process for preparation of polymer encapsulated nano sulphur fungicide (2011)
			Nanoencapsulated hexaconazole: A novel fungicide and the process for making the same (2011)
2	China	1	Nano-fertilizer pesticide synergist and preparation method (2015)
3	USA	3	Nanoformulations for plants (2017)
			A nano sulphur containing composition and application thereof (2018)
			Dispersible sulphur fertilizer pellets (2014)
4	South Korea	2	Method for preparing aqueous nanosulfur composition for liquid fertilizer (2017)
			Water-soluble nano-sulfur solution and manufacturing method thereof (2013)
5	Sri Lanka	1	Convenient and cost-effective novel strategy to synthesize nano-sulfur (2018)
6	New Zealand	1	Agricultural composition comprising an active sulphur ingredient (2015)

Industrial applications of sulphur

115. What are the industrial applications of sulphur?

Sulphur is used in many industries including non-ferrous metals, pigments, fibres, hydrofluoric acid, carbon disulphide, pharmaceuticals, agricultural pesticides, chemicals, explosives, fertilizers, personal care products, cosmetics, paint, paper, synthetic rubber vulcanization, sugar, water treatment and steel pickling.

116. Which are the industrial sources of sulphur?

The industrial sources of sulphur are natural gas refineries, petroleum refineries, pyrites and smelter gases from the processing of copper, zinc and lead ores. In most cases, sulphur is separated from other gases like hydrogen sulfide and then converted to elemental sulphur by the 'Claus Process'. Another important source of industrial sulphur is the sulphur dioxide emitted into the atmosphere by coal-fired steam power plants.

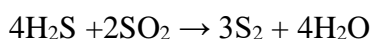
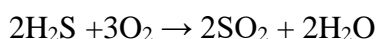
117. Which are the drugs that can be prepared from sulphur?

Sulfonamides, Thioethers, Sulfones and Penicillin are the most common drugs made from sulphur.

118. What is Claus process to recover elemental sulphur?

Claus process is a process in which hydrogen sulphide (H_2S) is separated from impure copper, zinc and lead ores. The obtained hydrogen sulphide (H_2S) is partially burnt to form sulphur dioxide. Then it is followed by a subsequent reaction between hydrogen sulphide (H_2S) and sulphur dioxide which yield elemental sulphur.

The reactions are as follows:



119. What is the Frasch process for mining sulphur?

Frasch process is a method of mining deep-lying sulphur in which superheated water (170°C) is forced into the deposit to melt the sulphur (melting point is $111\text{-}115^\circ\text{C}$), which is lifted to the surface by means of compressed air.

120. What measures should be taken while handling molten sulphur in industries?

To handle molten sulphur properly and to prevent solidification in industries, all lines and equipment must be heated. Steam jacketing is necessary as well as all the equipment and storage tanks should be fitted with steam coils.

121. What precautions should be taken while handling solid sulphur in industries?

While handling solid sulphur, water should be sprayed on sulphur to reduce the amount of dust generated in order to avoid the possibility of explosions and fires. Sulphur dust suspended in air is readily ignited by flame, static electricity or friction spark.

122. What should be the moisture content of solid sulphur used in industries?

The moisture content of solid sulphur should be maintained between 0.5 to 1.5%. Higher moisture contents will lead to less efficient melting since any water in the sulphur must be evaporated in the melter.

123. What are the factors affecting the generation of sulphur dust in industries?

The factors upon which the generation of sulphur dust in industries depends are:

- 1) Form (flakes, prills, pastilles, etc.) of sulphur
- 2) Moisture content
- 3) Handling methods
- 4) Equipment employed

124. What are the methods to reduce the amount of dust generated while handling solid sulphur in industries?

Sulphur dust which is generated while handling solid sulphur can be controlled by the use of water sprays. Sprays should be generally located at transfer points in the system, such as at the end of conveyors or outlet of hoppers. Special dust suppression agents can also be used to improve the suppression of sulphur dust.

125. Why consumption of sulphur is regarded as a reliable indicator of industrial activity and the state of the national economy?

Consumption of sulphur is regarded as a reliable indicator of industrial activity and the state of the national economy because more than 80% of all the sulphur produced is converted into sulphuric acid, for which the single largest use is in the manufacture

of fertilizers (phosphates and ammonium sulphate). Sulphuric acid is also known as the “king of chemicals” because of its wide application in the manufacture of other acids such as Hydrochloric acid (HCl), Nitric acid (HNO₃), fertilizers, laboratory reagents, industries, etc.

126. How is sulphuric acid produced?

Sulphuric acid is produced by burning sulphur in the presence of air to obtain Sulphur dioxide. Sulphur dioxide is then converted to sulphur trioxide in presence of vanadium pentoxide catalyst. The obtained sulphur trioxide is absorbed in sulphuric acid to give Oleum (H₂S₂O₇) which is further diluted to give sulphuric acid.

127. How pure sulphur is obtained in industries?

Because of the low melting point of sulphur (115°C), pure sulphur is obtained by distillation. However, for research purposes, 99.99% pure sulphur is obtained by procedures such as zone melting, column chromatography, electrolysis, or fractional distillation.

128. How much percentage of total sulphur emission in the atmosphere is contributed by anthropogenic activities?

Anthropogenic activity accounts for 75% of the total sulphur emission in the atmosphere.

129. What is acid rain?

When the pH of the rainwater drops below 5.6, it is called acid rain. Acid rain is rain or any other form of acidic precipitation occurring when sulphur dioxide (SO₂) and nitrogen oxides (NO_x) emitted into the atmosphere, react with water, oxygen or other chemicals to form sulphuric and nitric acids. These then mix with rainwater and dust particles before falling to the ground as rainwater.

130. What is the use of sulphur in batteries preparation?

Elemental sulphur is used as the cathode active material in batteries which contain at least 70% sulphur. The main advantage of using sulphur in batteries is its low cost and high energy density of 2500 Wh kg⁻¹.

131. What is the use of sulphur in highway/road construction?

Sulphur is combined with asphalt to make paving material for the construction of highways. There are four different types of sulphur paving materials: sulphur-extended asphalt binders, sand–asphalt–sulphur, sulphur concrete and sulphur polymer cement.

132. What is sulphur concrete?

Sulphur concrete is a relatively new corrosion-resistant material that contains stones, sand, mineral filler, and sulphur polymer cement (chemically modified sulphur) binder. Sulphur concrete is mixed and placed at an elevated temperature. It rapidly gains high strength over a few hours of cooling and provides an economic, long-term performance in many harsh environments.

133. What is sulphur asphalt (bitumen)?

Sulphur asphalt, also known as bitumen is an alternative for asphalt road binder, in which sulphur is used to extend asphalt materials as a means of energy conservation. Sulphur asphalt can be used as a paving material and for the construction of roads.

134. What is meant by vulcanization?

Vulcanization is a process carried out for the hardening of rubber which consists of heating a mixture of raw rubber with sulphur at a temperature range between 140 °C to 160°C. 5% sulphur is used for the vulcanization of rubber. On vulcanization, sulphur forms cross-links at the reactive sites of double bonds and thus rubber gets stiffened.

135. Why sulphur is used in gunpowder?

Sulphur while serving as a fuel also lowers the temperature required to ignite the mixture in gunpowder, thereby increasing the rate of combustion. The proportion of sulphur in gunpowder is 10% by weight.

136. What is the sulphite process for making paper?

The sulphite process is a chemical process for the manufacture of paper pulp that employs an acid bisulphite solution to soften the wood material by removing the lignin from the cellulose.

137. What is the use of sulphur in paper industries?

Paper products account for about 2% of sulphur demand. The largest single segment of demand is in the manufacture of wood pulp by the sulphite process.

138. What is the use of sulphur in iron and steel production?

Sulphur is used in the iron and steel industry as sulphuric acid as a pickling agent to remove mill scale, rust, dirt, and grease from the surface of steel products prior to further processing.

139. What are the different gases produced during the purification of sulphur-containing organic materials?

Hydrogen sulphide (H_2S) and smaller amounts of other sulphur gases such as methanethiol (CH_3SH), dimethyl sulphide ($(CH_3)_2S$), dimethyl disulphide ($(CH_3)_2S_2$), carbonyl sulphide (COS), and carbon disulphide (CS_2) are produced during the purification of sulphur containing organic materials such as proteins and amino acids.

140. What is the percentage contribution of ore smelting and petroleum refining in industrial sulphur emission?

Ore smelting and petroleum refining account for 11% and 4% of total sulphur emissions, respectively.

141. What is the use of sulphur in plastic and other synthetic products?

Sulphur with suitable treatment can change from its usual ring-like chemical structure to long chains. These chains of sulphur can be joined together to create a solid plastic or rubber using other organic molecules to link them together.

142. What is the use of sulphur for mortar substitution?

Sulphur slime is used as a partial substitute for natural fine aggregate (sand) in mortar. Sulphur slime is a solid material consisting mainly of elemental orthorhombic sulphur with some impurities like gypsum and anhydrite.

Miscellaneous

143. Which country is the leading producer of sulphur in the world?

China is the leading producer of sulphur in the world.

144. Which countries are the world's largest importers and exporters of sulphur?

China is the world's largest importer of sulphur, followed by Morocco and Brazil, whereas Canada is the largest exporter of sulphur, followed by Russia and United Arab Emirates.

145. What was the annual sulphur production in India?

The annual sulphur production was about 880.90 thousand metric tonnes in 2021-22.
(Source:<https://www.statista.com/statistics/1031181/sulfur-production-globally-by-country/>).

146. Which are the sulphur producing states in India?

Odisha, Haryana, Kerala, Gujarat, West Bengal, Maharashtra, Uttar Pradesh, Bihar and Assam are the major sulphur producing states in India.

147. Name few industries dealing with sulphur manufacturing and marketing in Maharashtra?

Jayshil Sulphur & Chemical Industries (Mumbai), Sulphur Mills Ltd. (Mumbai), Yogalila Sulphur and Agache Indo Pvt. Ltd. (Mumbai), Devdhar Chemicals Pvt. Ltd. (Pune) are the few industries dealing with sulphur manufacturing and marketing in Maharashtra.

Multi location field trials of nano sulphur



ICAR-Directorate of Onion and Garlic Research (DOGR), Rajgurunagar



ICAR-Indian Institute of Soil Science (IISS), Bhopal



Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri



M/s Devdhar Chemicals Private Limited, Pune

Linkages



ICAR-CIRCOT, Mumbai and M/s Devdhar Chemicals Private Limited, Pune signs MoU for “Evaluation of ICAR-CIRCOT Nano sulphur as Fertilizer and Pesticide” on 27th October 2021



ICAR-CIRCOT, Mumbai inks MoU with MPKV, Rahuri, Maharashtra for “Efficacy Evaluation of ICAR-CIRCOT Nano sulphur as Fertilizer Formulation for different Field Crops” on 31st March 2022

Instrumentation facility at ICAR-CIRCOT



National Laboratory for Advanced Material Characterization



Atomic Force Microscope (AFM)



Scanning Electron Microscope (SEM)



Particle Size Analyzer



Goniometer



Nanocellulose Pilot Plant at ICAR-CIRCOT, Mumbai



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