FOOD SCIENCE AND TECHNOLOGY

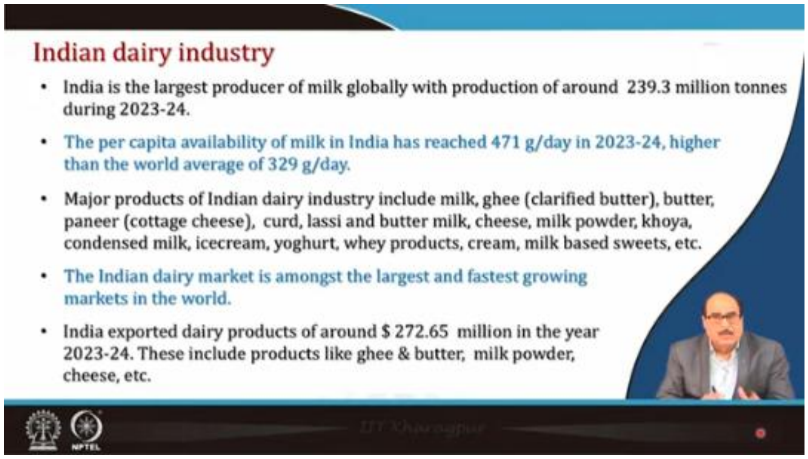
Lecture60

Lecture 60: Dairy Industry Waste Utilization & Course Summing-up

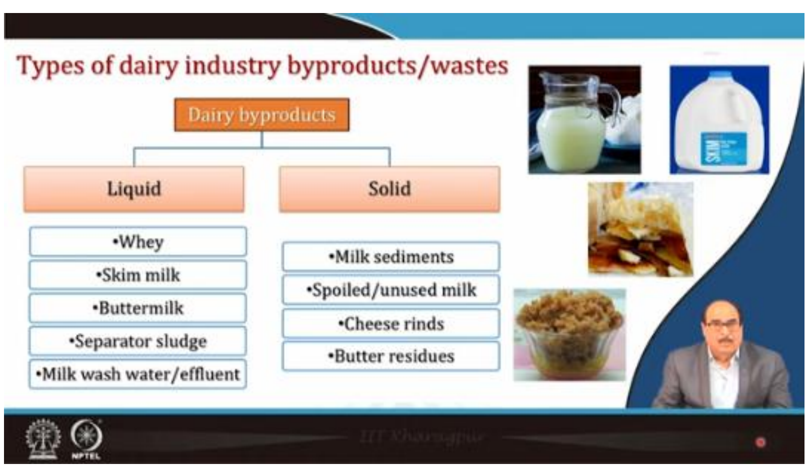
Hello everyone, Namaste.

Now, we are in the last lecture of this course, which is Lecture 60.

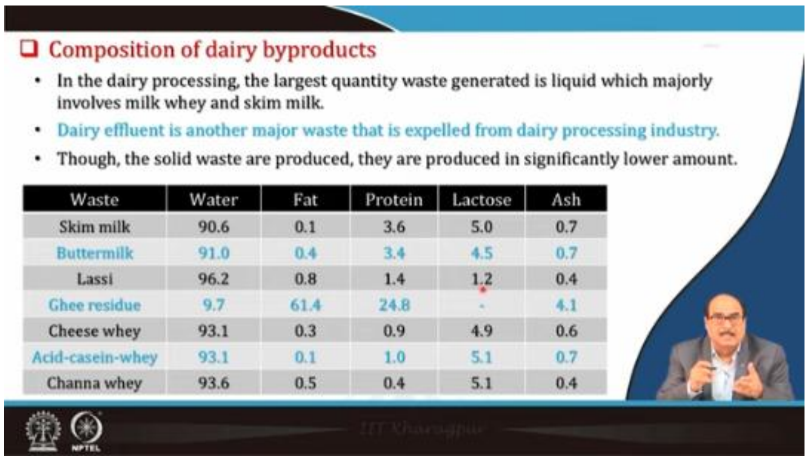
In the next half an hour or so, I will discuss dairy industry waste utilization and also devote some time to summarizing the entire course. We will talk about it a little bit. The Indian dairy industry: what is the current scenario, and therefore, dairy industry byproduct production and its utilization. We will also discuss dairy processing effluents and their treatment, biotechnological approaches to dairy waste conversion, and finally, as I mentioned, we will cover the course summary and acknowledgments.



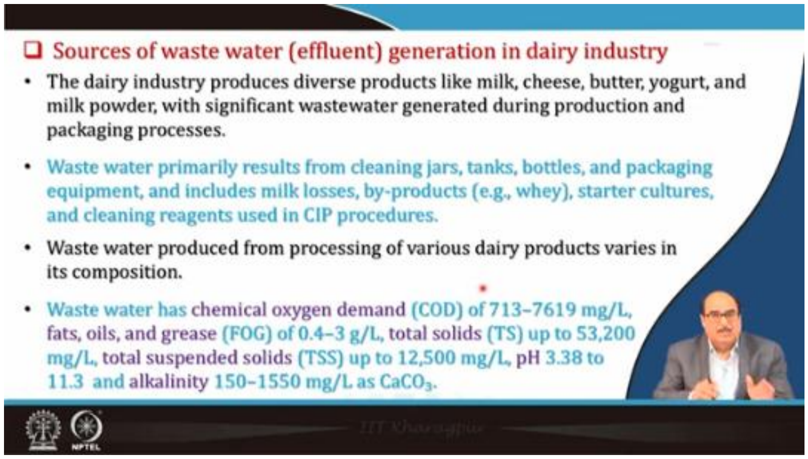
So, let us see what the current scenario of the Indian dairy industry is. I hope you know it is a proud moment for all of us that India is the largest producer of milk globally, with production of around 239.3 million tons during 2023 and 2024. The per capita availability of milk in India has reached 471 grams per day in 2023-24, which is higher than the average world consumption of milk, as the world average is 329 grams per day. Major products of the Indian dairy industry include milk, butter, paneer, curd, lassi, buttermilk, cheese, milk powder, khoya, condensed milk, ice cream, yogurt, whey protein, cream, milk-based sweets, and so on. So, the Indian dairy market is among the largest and fastest-growing markets in the world. India exported dairy products worth around US $ 272.65 million in the year 2023-24, and these exports included products like ghee, butter, milk powder, cheese, and so on.



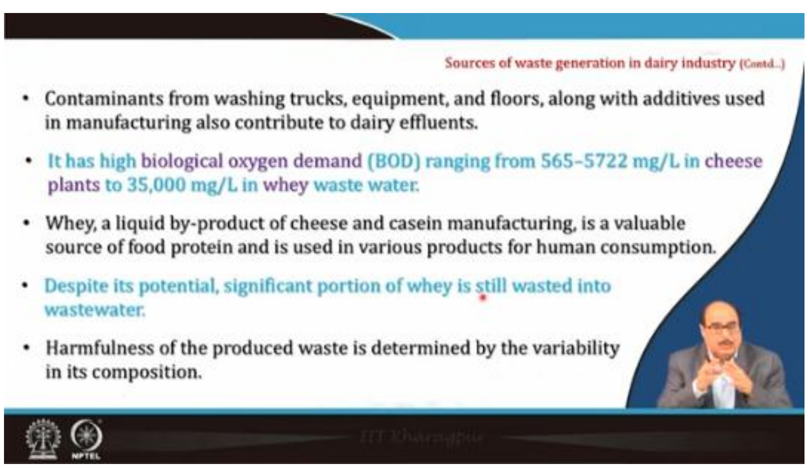
So, obviously, in any sector where such a wide dairy processing industry produces such a large quantity of products, it naturally results in various byproducts and wastes. So, the byproducts generated from the dairy industry can be segregated into liquid wastes or liquid byproducts and solid byproducts. Liquid byproducts include whey, skim milk, butter milk, even separator sludge or milk wash water or which you call effluent. The solid waste includes milk sediments, spoiled or unused milk, cheese rinds and butter residues.



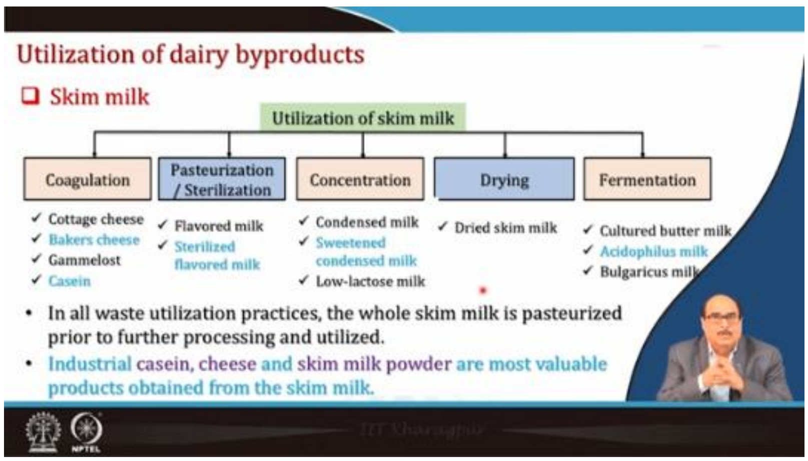
So, these all if you look at the composition of these products obviously, there is the in the dairy processing largest quantity waste generated is liquid, and the majority or majorly involves that is the of the liquid waste significant proportion major amount is milk whey and skim milk. Dairy effluent is another major waste that is expelled from the dairy processing industry, and although the solid waste are produced in the dairy industry, but they are significantly produced in the lower amount they are significantly lower amount they are produced. So, the various type of waste like skim milk and these wastes whatever the waste is produced they contain lot of valuable components. For example, skim milk it contains around 3.6 percent protein, 5 percent lactose and 0.7 percent ash, butter milk contains around 0.4 percent fat, 3.4 percent protein, 4.5 percent lactose and 0.7 percent ash. Similarly, even ghee residue it contains around 24.8 percent protein and 4 percent ash. Cheese whey contains around 5 percent lactose and that is around 0.6 percent ash. Acid-casein-whey contains around 5 percent lactose. Channa whey contains around again 5 percent lactose. So, these components, this waste materials etcetera that is are byproducts, they can be utilized effectively for various purposes.



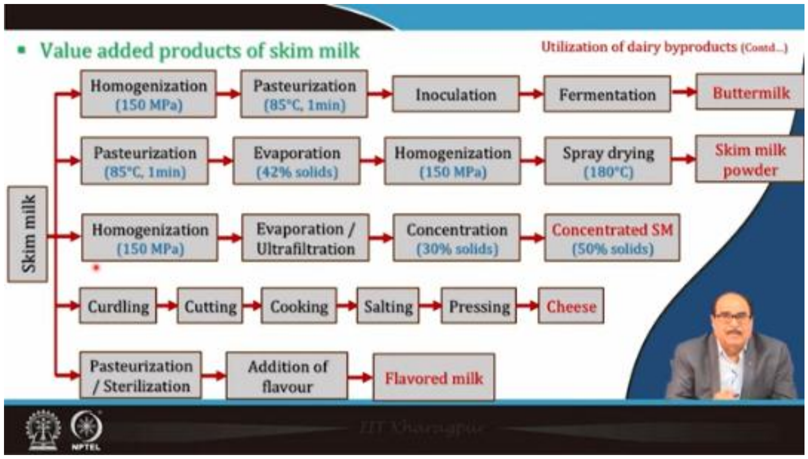
So, if you look at the sources of the waste water that is effluent generation in the dairy industry, because the dairy industry produces diverse products which we discussed earlier also the like milk, cheese, butter, yogurt, milk powder. So, it generates also significant amount of waste water particularly during starting from production till it is packaged. And, this waste water primarily results from the cleaning jars, tanks, bottles and packaging equipment cleaning. It includes even milk losses, spoiled milk or by-products (whey), starter cultures and cleaning reagents which are used in the CIP procedures etcetera. And these waste water produced from processing of various dairy products varies in its composition, and therefore, it contains like this waste water has COD value i.e. chemical oxygen demand very high ranging from 713 to 7619 milligram per liter. It has FOG value like fats, oil and grease content of around 0.4 to 3 gram per liter. Total solids content up to 53200 milligram per liter, total suspended solids up to 12500 milligram per liter, it may pH may vary from 3.38 to 11.3, its alkalinity may be ranging from 150 to 1550 milligram per liter as calcium carbonate etcetera.



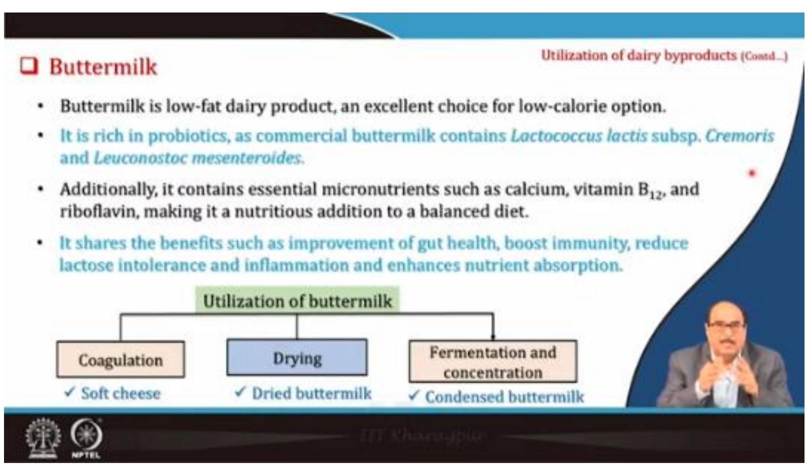
So, these contaminants which come from washing the trucks, equipment and floors along with additives etcetera used in manufacture also contribute to dairy effluents. So, these contaminants have high BOD value raising that is the even this it contains that 565 to 5722 milligram per liter in cheese plants as well as up to 35000 milligram per liter in whey waste water. Whey which is a liquid byproduct of cheese and casein manufacturing, is a valuable source of food protein and is used in various products preparation formulation for human consumption for beverages and so on. So, of course, despite its potential significant portion of whey is still wasted into waste water or thrown away. So, there is a lot of potential of using this whey and also the harmfulness of this product wastes is determined by the variability in its composition.



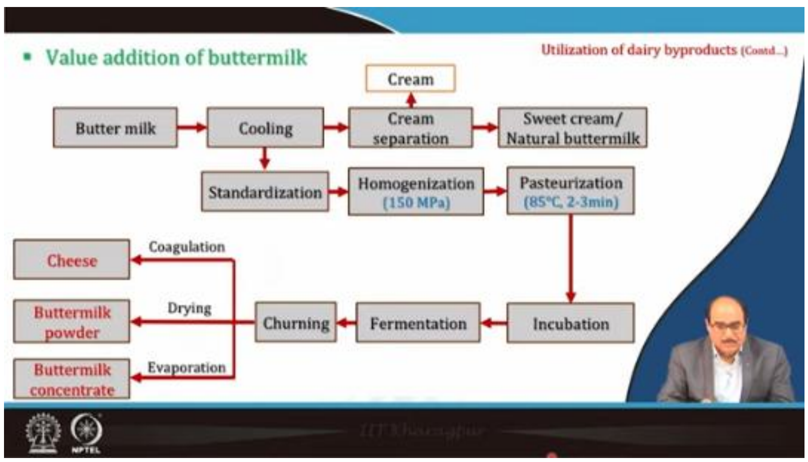
And so, there should be a proper and effective mechanism for its utilization; otherwise, it will create environmental pollution and hazards. So, let us talk about utilization—how these byproducts, etc., of the dairy in processing can be effectively utilized. So, first is the skim milk. So, this skim milk can be used for various purposes, like it can be coagulated to prepare cottage cheese, baker's cheese, gammelost, casein, etc. It can be used for the preparation of flavored milk or sterilized milk. Or it can be concentrated into condensed skim milk, sweetened condensed milk, or low-lactose milk. Or dried into dried skim milk powder, or it can be fermented to make cultured buttermilk, acidophilus milk, bulgaricus milk, and so on. So, in all cases, you can say, obviously, the whole skim milk is first pasteurized prior to further processing and utilization. And in industrial cases, casein, cheese, and skim milk powders, these three are the most valuable products obtained from skim milk processing.



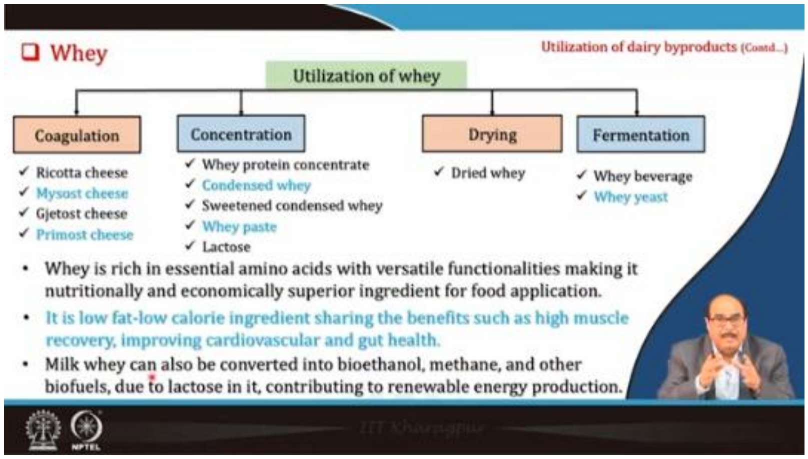
So, the value-added product, that is, the process flow, which can be made from the skim milk. That is, this skim milk can be homogenized at 150 megapascals of pressure, pasteurized at 85 degrees Celsius for 1 minute. Inoculated with the dairy culture, lactic acid bacteria, fermented, and you get the buttermilk. Similarly, it can be pasteurized, evaporated, homogenized, and dried, i.e., spray-dried at around 180 degrees Celsius, etc. into skim milk powder. Or skim milk can be homogenized, evaporated, ultrafiltered, concentrated, you can get concentrated skim milk. Or, that is, it can be curdled, cut, cooked, salted, and pressed, you get the cheese because skim milk has a good quantity of protein. So, it can be used for manufacture of cheese and then skim milk can be pasteurized, sterilized, added with the flavor and you get flavored milk. So, various product flavored milk, cheese, concentrated skim milk, skim milk powder, buttermilk all these can be produced, and they are produced by the industry they are available in the market also some that is the dairy advanced dairy they are using all these products.



Then buttermilk it is a low-fat dairy product and excellent choice for low calorie option. It is rich in probiotics as the commercial buttermilk contains *Lactococcus lactis* subspecies *Cremoris* and *Leuconostoc mesenteroides*. Additionally, it contains essential micronutrients such as calcium, vitamin B_{12} and riboflavin and making it a nutritious addition to a balanced diet. Buttermilk shares the benefits such as improvement of gut health, boost immunity, reduce lactose intolerance and inflammation and enhances nutrient absorption. So, this buttermilk again can be utilized for making soft cheeses, for drying into dried buttermilk powder or dried buttermilk product and it can be fermented and concentrated to make condensed buttermilk.

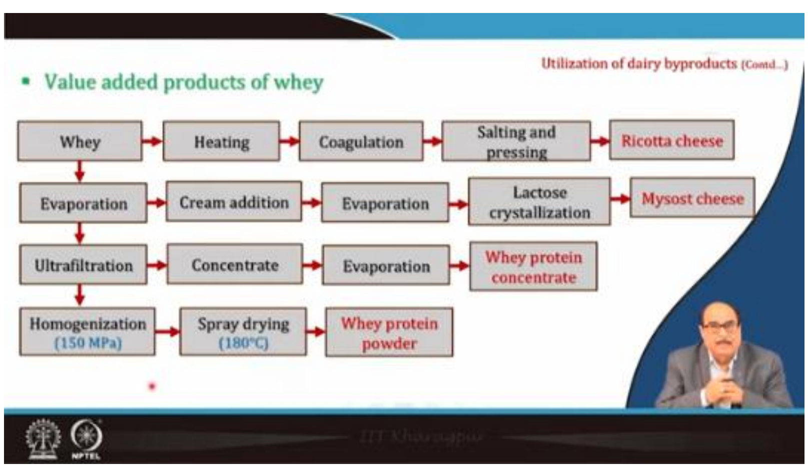


So, the value addition in this buttermilk is that yes you can take buttermilk, cooled, cream separation, and sweet cream, and natural buttermilk or after cooling you standardize it, homogenize, pasteurize, incubate with the incubation at a particular temperature, fermented, churning, and then it can be coagulated cheese product, dried buttermilk powder, or evaporated into buttermilk concentrate. So, the end product may be cheese, buttermilk powder, or buttermilk concentrates.

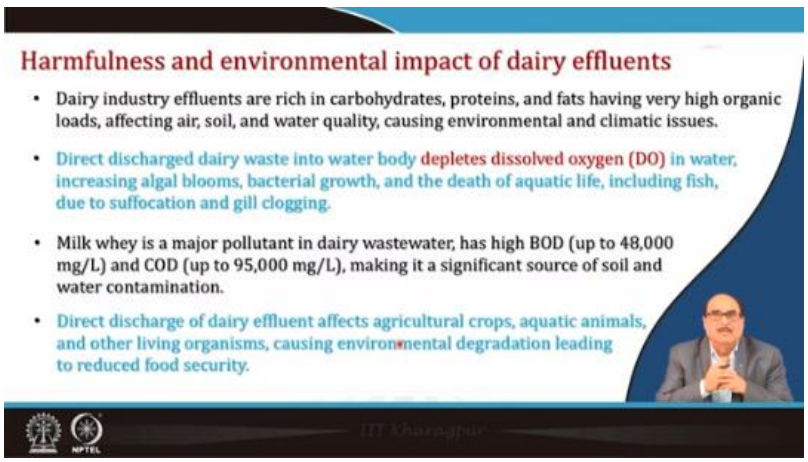


Then the whey is another important byproduct of paneer making industry or cheese making industry. So, this whey again it contains very good amount of lactose, it contains very amount of whey globulin etcetera, other proteins. So, it can be used for making different types of cheeses like ricotta cheese, mysost cheese and primost cheese etcetera.

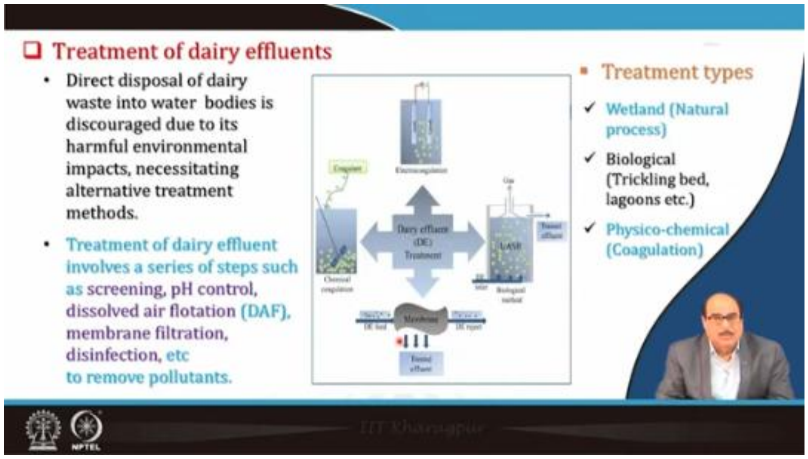
It can be concentrated into whey protein concentrate, condensed whey, sweetened condensed whey, or made into whey paste or lactose crystallization to extract lactose from it. So, it can be dried. Thus, we have dried whey, or it can be fermented or used in various fermented beverages or even whey yeast. So, this whey is also rich in essential amino acids with versatile functions, making it a nutritionally and economically superior ingredient for different food applications. It is a low-fat, low-calorie ingredient, offering benefits such as high muscle recovery, improved cardiovascular health, and better gut health. Milk whey can also be converted into bioethanol, methane, and other biofuels due to its lactose content, contributing to renewable energy production.



So, again, whey has a lot of potential for utilization in various value-added products. So, the value-added products from whey may include ricotta cheese, mysost cheese, whey protein concentrate, whey protein powder, etc. And this process involves general steps like heating, coagulation, salting, pressing, evaporation, cream addition, and lactose crystallization to make mysost cheese. Or ultrafiltration, concentration, and evaporation for whey protein concentrate formation. Or homogenization and spray drying for making whey protein powders. So, these are the steps, and as I mentioned earlier, many advanced technologies are using these products. So, technologically, even commercial processes are available for the manufacture of these products.

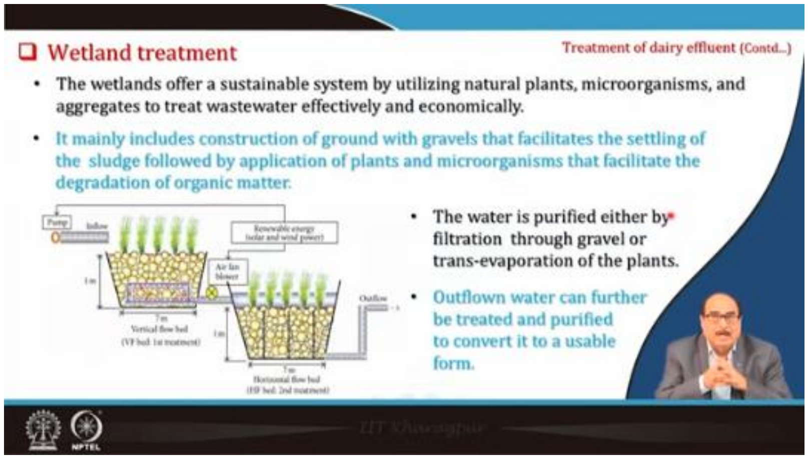


So, let us briefly discuss the harmfulness and environmental impact of dairy effluents. Obviously, as you have seen earlier, dairy effluents have high COD values, high BOD values, etc. And directly discharging dairy waste into water bodies depletes dissolved oxygen in the water, increasing algal bloom, even that is causing bacterial growth and the depth of aquatic life including fish etcetera is a lost that is the aquatic life is died or fishes etcetera and this is mainly due to the suffocation and gill clogging because of the high depleted dissolved oxygen. Milk whey is a major pollutant in dairy waste water. It has a high BOD up to 48000 milligram per liter and high COD up to 95000 per liter and making it a significant source of soil and water contamination. Even the, but the same time dairy industry effluent, they are also rich in carbohydrate, proteins and fat having very high organic loads affecting air, soil and water quality causing environmental and climatic issues. Direct discharge of dairy effluent affects agricultural crops, aquatic animals and other living organisms causing environmental degradation leading to reduced food security.

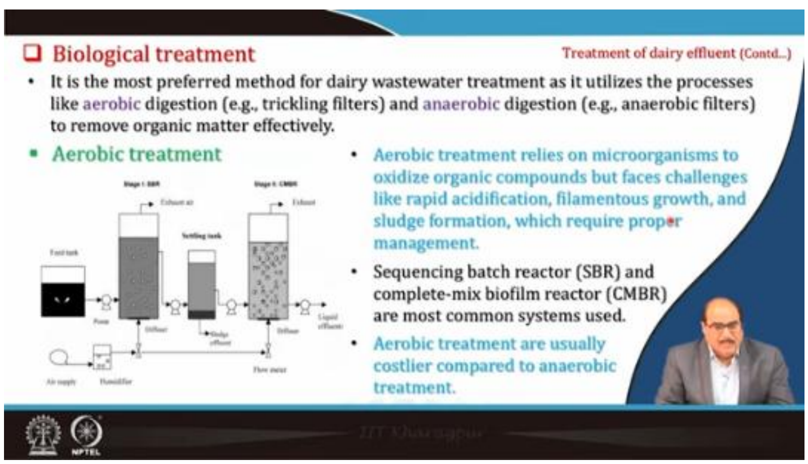


So, it becomes a very very important one should have a proper mechanism for the effluent treatment dairy effluent treatment. So, what are the different there are different approaches different method for the treatment of dairy effluent. that like direct disposal of the dairy waste water into water bodies is discouraged. mainly due to it is a harmful environmental impact, necessitating alternative treatment method that is it should not be directly exposed to environment or in the water body.

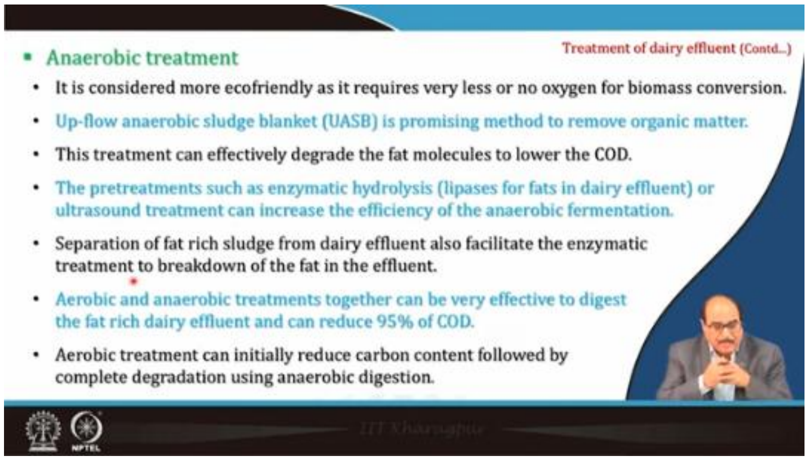
It should be collected and sent for the proper treatment and the treatment of very effluent it involves a series of steps such as its screening, its pH control, its dissolved air flotation, membrane filtration, disinfection etcetera to remove the different types of pollutants which might be present there like it may be electrocoagulation, chemical coagulation, biological methods or membrane filtration etcetera can be used to purify or treat the dairy effluent. The different types of the treatment methods may be wetland method like natural process or biological method like trickling bed, lagoons etcetera or even physicochemical methods like coagulation is used.



So, the wetland method, it offers a sustainable system by utilizing natural plants, microorganisms and aggregates to treat waste water effectively and economically. It mainly includes construction of ground with gravel that facilitates the settling of the sludge followed by application of plant and microorganism that facilitates the degradation of the organic matter which is there in the effluent. The water is purified either by filtration through gravel or trans-evaporation of the plant. And outflown water can further be converted and purified to convert it into a suitable form for using agriculture or using for various purposes.

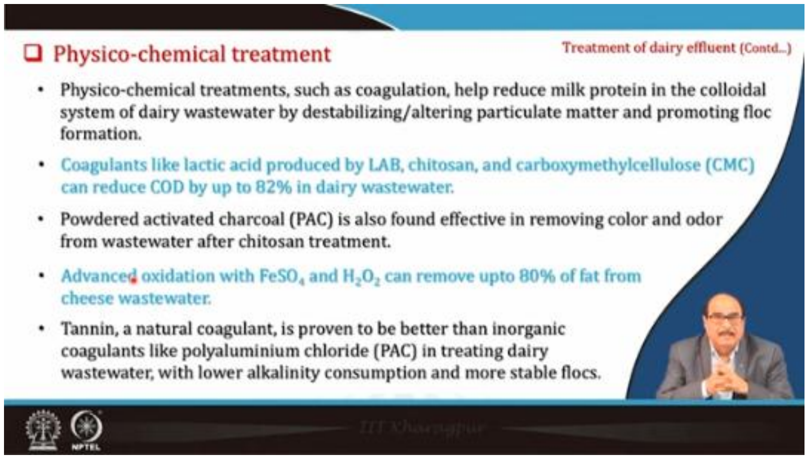


Then biological treatment, it is the most preferred method for dairy wastewater treatment as it utilizes the process like aerobic digestion using trickling filters or anaerobic digestion using anaerobic filters etcetera. And in this way either by aerobic methods or by anaerobic methods the organic matters are most effectively utilized or removed. So, in the aerobic methods as you can see here in this diagram, that this method mainly relies on the microorganisms to oxidize organic compounds, but faces challenges like rapid acidification filamentous growth and sludge formation which require proper management. And, the sequencing batch reactors (SBR) or even that complete mixed biofilm reactors are the most commonly used systems which are used for the aerobic treatment. And, this aerobic treatment is usually costlier compared to anaerobic treatments.



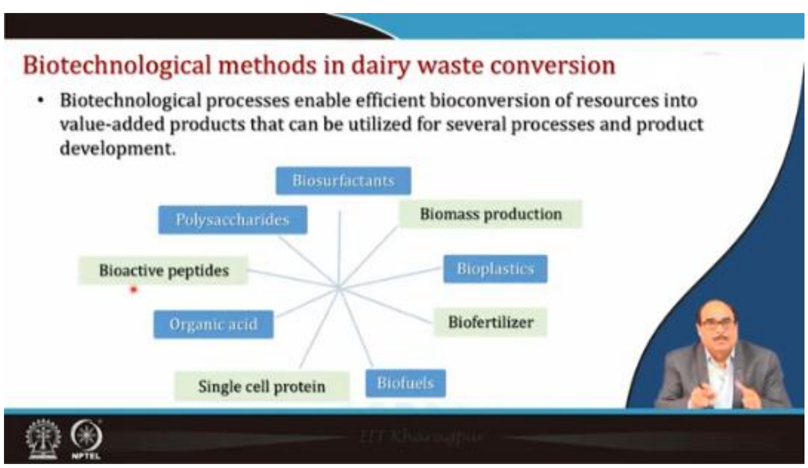
Anaerobic treatment is considered more economical as it requires very less or even no oxygen for biomass conversion. Up-flow aerobic sludge blanket that is UASB is a promising method to remove organic matter. This treatment can effectively degrade the fat molecules to lower the COD value. The pretreatments such as enzymatic hydrolysis by using lipase etcetera for the hydrolysis of fats are using is treating it with the ultrasounds. This can increase the efficiency of the anaerobic fermentation.

Even the separation of fat-rich sludge from dairy effluent facilitates the enzymatic treatment to break down the fat in the effluent. Aerobic and anaerobic treatments together can be very effective in digesting the fat-rich dairy effluent, and they can reduce the COD value by up to 95 percent of its original value. Aerobic treatments can initially reduce carbon content, followed by complete degradation using anaerobic digestion.

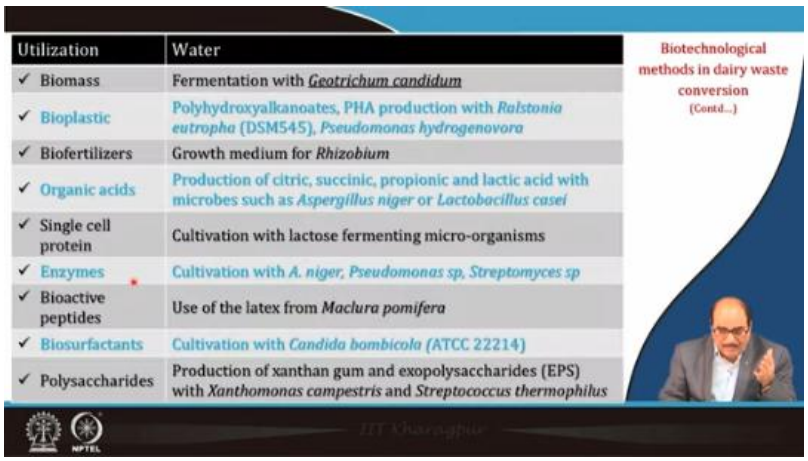


The physicochemical treatment, such as coagulation, helps reduce milk protein in the colloidal system of dairy wastewater by destabilizing or altering particulate matter and promoting floc formation. Coagulants like lactic acid, which are produced by lactic acid bacteria, and even chitosan, carboxymethyl cellulose, all these can be used to reduce the COD value by up to 82 percent in dairy wastewater. Even powdered activated charcoal (PSE), commonly known as such, is also found effective in removing color and odor from the wastewater after chitosan treatment. So, if the wastewater is treated with chitosan and then passed through activated charcoal, it is used. So, it removes the color and flavor. Advanced oxidation with ferrous sulfate and hydrogen peroxide can remove up to 80 percent of the fat from cheese wastewater.

Tannin, which is a natural coagulant, is proven to be better than inorganic coagulants like polyaluminum chloride in treating dairy wastewater, with lower alkalinity consumption and more stable flocs.

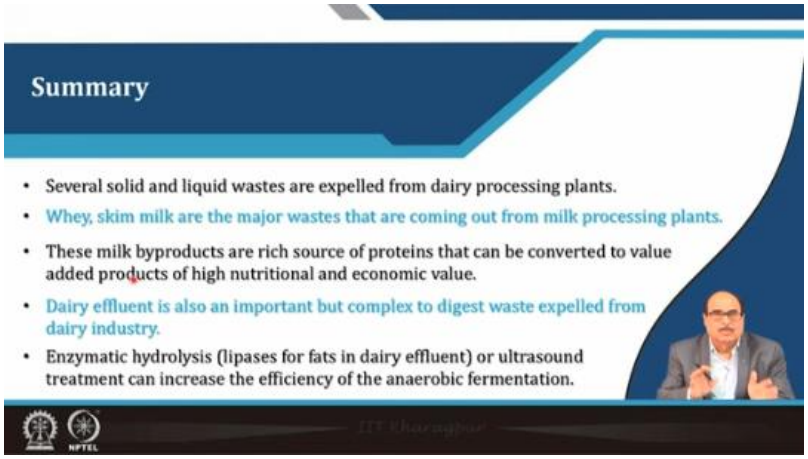


So, now let us briefly talk about the biotechnological methods in dairy wastewater conversion. These biotechnological processes enable efficient or effective bioconversion of resources into value-added products, which can be utilized for several processes and product development, such as for biosurfactants, biomass production, and even for production as bioplastics, biofertilizers, biofuels, as single-cell protein for the production of organic acids, bioactive peptides, polysaccharides, etcetera. So, there are various biotechnological methods and processes already developed by researchers, and they are in the public domain, with many industries using them.



Here, even the utilization of biomass, such as fermentation with *Geotrichum candidum*, or for bioplastics like PHA production with *Ralstonia eutropha* or *Pseudomonas hydrogenovora*, or it can be used for biofertilizers, organic acids, or even single-cell protein cultivation with lactose-fermenting microorganisms, enzymes like those cultivated with *Aspergillus niger*, *Pseudomonas species*, etc. Bioactive peptides can be derived from the latex of *Maclura pomifera*, biosurfactants from *Candida bombicola*, or polysaccharides like xanthan gum and exopolysaccharides from various microorganisms.

So, there are various biotechnological processes available that can be used for the effective treatment of dairy effluent, and these can further be utilized in various products across food, pharmaceutical, packaging, and other industries.

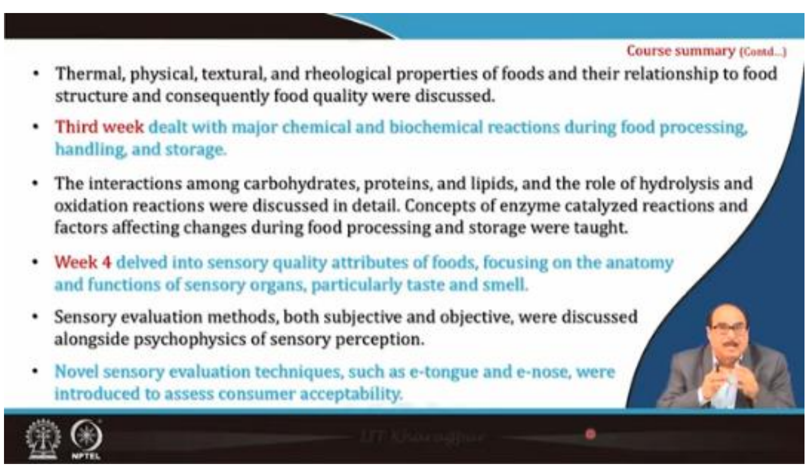


So, finally, the summary of this lecture, particularly regarding the utilization of dairy industry waste, is that, as I mentioned earlier, various solid and liquid wastes are generated in dairy processing. Whey and skim milk are the major wastes produced in milk processing plants. These milk byproducts are rich sources of proteins that can be converted into value-added products with high nutritional and economic value. Dairy effluent is an important but complex waste expelled from the dairy industry, and a significant amount is produced. It must be managed to add value through resource utilization and to prevent contamination or environmental pollution. Enzymatic hydrolysis or ultrasound treatment can increase the efficiency of anaerobic fermentation, or methods like physical, chemical, biochemical, and biotechnological processes can be applied to effectively utilize dairy industry effluents. Treat the effluents of the dairy processing as well as utilize the by-products of the dairy industry for useful purposes in various foods, various feeds, and various pharmaceutical applications. And that is where it will lead to the circular economy and all it will lead to a circular economy.

So, these were the references which were used in making this lecture.

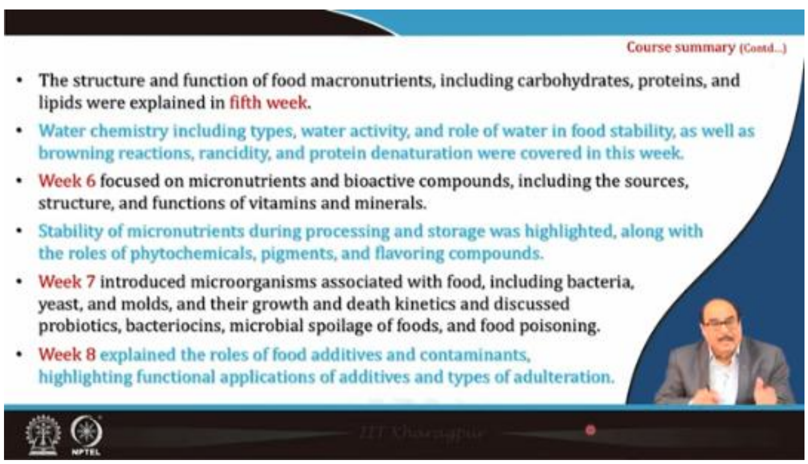
Now, I will briefly tell you about the summary of the course, that is, what I would like to summarize in the next 5 or 7 minutes, which is what we discussed in this whole 12-week course.

So, obviously, if you remember, the first week the course commenced with the introduction, followed by explaining the types of foods, their production and processing challenges, and the impact of global warming on food systems along with the strategies for managing food losses. The first week covered the energy and nutritional value of foods, the importance of balanced diets, and issues of affordability and accessibility of various food items. Additionally, it also emphasized consumer awareness, behavior, and technological or resource barriers in achieving sustainable food systems. In the second week, the focus was on the food structure-function relationship, including food quality characteristics and the chemical composition of major food produced in India.



Thermal, physical, textural, and rheological properties of major foods and their relationship to food structure and consequently food quality were discussed. The third week dealt with major chemical and biochemical reactions during food processing, handling, and storage. The interaction among the food carbohydrates, proteins, and lipids, that is, the major macronutrients which are present in the food, and the role of macronutrients, various reactions, chemical reactions, chemical transformations like hydrolysis and oxidative reactions, we have discussed in detail. Even concepts like enzyme-catalyzed reactions and factors affecting changes during food processing and storage were also taught.

Week 4 delved into sensory quality attributes of food. It focused on the anatomy and functions of sensory organs, particularly the taste and smell organs. Sensory evaluation methods, both subjective and objective, were discussed alongside the psychophysics of various sensory perceptions. Even novel sensory evaluation techniques such as e-tongue, e-nose, etcetera, were introduced to assess consumer acceptability. So, both objective methods as well as subjective methods and novel approaches of sensory evaluation were discussed.

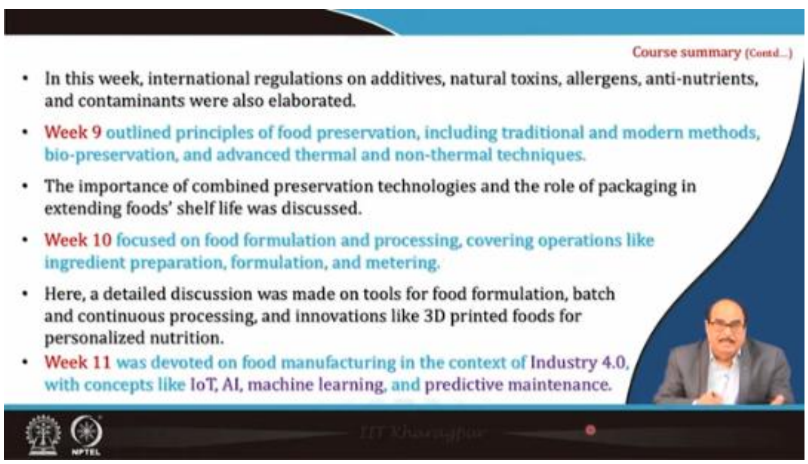


The structure and functions of food macronutrients, including carbohydrates, proteins, and lipids, were explained in the fifth week. Here, water chemistry, including the types of water, water activity, the role of water in food stability, as well as various browning reactions, rancidity, protein denaturation, and so on. All these major processes in the food, coming out of the macronutrients, were covered in the fifth week.

Week 6 focused on micronutrients and bioactive compounds, including the sources, structure, and functions of vitamins and minerals. Stability of micronutrients, particularly vitamins and minerals. And other minor components like flavors, enzymes, pigments, etcetera, were studied, that is, during processing and storage, etcetera, all these, how these micronutrients are stable, it was highlighted.

Also, the role of phytochemicals, pigments, and flavoring compounds was discussed in week 6. Week 7 introduced microorganisms; we talked briefly about the various types of microorganisms associated with food, including bacteria, yeast, molds, etcetera, their growth and death kinetics. And also, we discussed probiotics, bacteriocins, microbial spoilage of food, and even food poisoning and intoxications—major aspects we discussed in week 7.

Week 8 explained the role of food additives and contaminants, highlighting functional properties of additives and the different types of adulterations and detection of adulterations in foods, etcetera, discussed in week 8.



In this week, we also talked about international regulations on additives, like even natural toxins, allergens, anti-nutrients, and contaminants, which were also elaborated in week 8.

Week 9 outlined principles of food preservation technologies and methods, including traditional and modern methods. Advanced thermal and non-thermal technologies, which are used commercially for food preservation purposes, and their principles and practices were briefly discussed in Week 9. The importance of combined preservation technologies and the role of packaging in extending food shelf life was also discussed in Week 9. Week

10 focused on food formulation and processing, covering operations like ingredient preparation, formulation, and metering. Various statistical models, etc., and how to design different types of food for personalized nutrition, among other things, were also discussed here.

A detailed discussion was also made on tools for food formulation, batch and continuous processing, and innovations like 3D-printed foods for personalized nutrition. Week 11 was devoted to food manufacturing in the context of Industry 4.0, with concepts like the Internet of Things, artificial intelligence, machine learning, and predictive maintenance. These concepts and their applications in the food industry, particularly in food processing, were all discussed in detail.

Topics such as process control, instrumentation in the food industry, the use of different sensors, and automation of food processes, like the use of robotics, were also discussed and covered in Week 11.

Week 12, which was the concluding week of the course, emphasized circularity in the food industry. It emphasized the concept of a circular economy in the food industry, focusing on waste recycling and reuse, as well as resource economy, waste reduction, reuse, and recycling. Sustainable sourcing, resource efficiency, and the valorization of food industry byproducts or waste especially from the grain processing industry, the fruits and vegetable processing industry, and the meat, fish, and poultry processing industry, as well as the dairy industry, which are the four major segments of the food processing industry, as they are the primary sources of waste streams and byproduct generation. Effective ways of utilizing these byproducts of the industry were discussed to cover the circular economy in the food industry.

And this was the overall course, and it was taught, and I hope you all enjoyed it.

So now, in the end, I would like to offer the acknowledgements.

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So, with this finally, I wish all the best and this great success in the to all the participants of this course for their future endeavors. I wish you all a very happy and successful professional as well as personal life ahead. Thank you all. Thank you very much.