Grenze International Journal of Engineering and Technology, June Issue

Separation and Detection of Sugar in Raw Milk for Dairy Applications

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***Abstract*— The primary objective of this project is to develop a simple, low-cost, and effective system for the separation and detection of sugar in raw milk. The project aims to address the growing health concerns related to diabetes, lactose intolerance, and obesity by producing low-sugar, high-protein milk. Specific goals include: (i) separating lactose and other naturally occurring sugars from whole milk using a semipermeable ultrafiltration membrane, (ii) accurately detecting and measuring sugar concentration levels before and after filtration using a conductivity-based method, (iii) retaining essential milk proteins, nutrients, and bioactive compounds during the filtration process, and (iv) designing a fully functional, low-cost prototype accessible to small-scale dairy farmers, rural cooperatives, and households. The system is completely hardware-based and requires no microcontroller or programming, making it easy to use and replicate. The project employs two core methodologies: detection and separation. For detection, a conductivity-based circuit is designed using two copper probes inserted into the milk sample. When adulterants such as sugar, water, or detergent are present, the electrical conductivity of the milk changes. This variation generates a small electrical signal between the probes, which is then amplified using a BC547 NPN transistor. The output is displayed through an LED, where brightness varies according to the level of adulteration—brighter glow indicates higher adulteration. For separation, the project utilizes an ultrafiltration membrane that selectively allows smaller sugar molecules (lactose) to pass through while retaining larger proteins, vitamins, and minerals. The membrane operates at room temperature to preserve heat-sensitive nutrients. The detection circuit is assembled on a breadboard using resistors (10kΩ and 220Ω), a BC547 transistor, copper probes, an LED, and a DC power supply (5–12V). Testing is conducted using pure and adulterated milk samples, with LED brightness recorded for comparisons. Lactose is a reducing sugar present in milk. When heated with Fehling's solution, lactose reduces cupric ions (Cu^{2+}) to cuprous oxide (Cu_2O), forming a brick-red precipitate. The amount of lactose present is determined by titrating the milk solution against Fehling's solution using volumetric analysis.**

***Index Terms*— Milk adulteration, Conductivity detection, BC547 transistor, Ultrafiltration membrane, Lactose reduction.**

Grenze ID: 01.GIJET.12.2.834_26

I. Introduction

The developed prototype successfully detects the presence of sugar and other ionic adulterants in raw milk through changes in LED brightness. Pure milk produces dim or no LED glow, while adulterated milk produces a bright LED glow, providing instant visual feedback. The system is sensitive to as little as 5–10% adulteration and works with various adulterants including sugar, water, and detergent. The ultrafiltration membrane achieved significant lactose reduction while retaining over 90% of milk proteins and essential nutrients. The entire system operates at low power (5–12V DC), is portable, and costs significantly less than commercial alternatives. Key outcomes include: a microcontroller-free, reusable, chemical-free detection system; real-time visual indication of milk purity; and a scalable membrane-based separation process for producing low-sugar, high-protein milk suitable for diabetics and lactose-intolerant individuals [1].

The system has wide-ranging applications including: dairy industry quality control, on-farm self-testing by small-scale farmers, household milk purity verification, food safety monitoring by regulatory agencies, and production of low-sugar dairy products for health-conscious consumers. It is also suitable for educational institutions as a STEM teaching tool. Future scope includes: temperature compensation using thermistors, digital display integration, IoT and smartphone connectivity for data logging, addition of pH and turbidity sensors, automated probe cleaning, solar power option for off-grid use, multi-stage membrane filtration for higher efficiency, AI-based adulteration classification, commercial manufacturing with PCB and protective enclosure, and obtaining regulatory certification (FSSAI/ISO) for official use [2].

II. Background

Milk is one of the most widely consumed and nutritionally complete foods, providing essential proteins, fats, carbohydrates (lactose), vitamins, and minerals, particularly calcium and vitamin D. It is a staple in the diet of millions of people, especially children, pregnant women, and the elderly. However, the rising demand for milk has led to widespread adulteration practices, where unscrupulous vendors and producers add water, sugar, detergent, starch, urea, formalin, and other harmful substances to increase volume or mask quality defects. Sugar adulteration, in particular, is common because it increases the sweetness and solids content of diluted milk, making it appear normal. Such adulteration not only reduces the nutritional value of milk but also poses serious health risks including diabetes, obesity, digestive disorders, and even long-term toxicity. The inability of consumers and small-scale dairy farmers to detect these adulterants easily and affordably has exacerbated the problem, making food safety a critical public health concern [3].

III. Problem Statement and Objectives / Scope

The problem statement of this project is as follows: Rising cases of diabetes, lactose intolerance, and obesity have increased demand for low-carbohydrate, high-protein dairy products. Conventional lactose-free milk still contains high sugar levels because lactose is converted into glucose and galactose instead of being removed. Existing membrane-based lactose reduction systems are expensive, energy-intensive, and difficult for small dairy industries to adopt. There is a need for a cost-effective membrane-based milk processing system that reduces lactose while retaining proteins and nutritional quality with minimal fouling and protein loss [4].

The objectives of this project are: (i) To systematically separate lactose and other naturally occurring sugars from whole milk using a semipermeable ultrafiltration membrane that selectively allows smaller sugar molecules to pass through while retaining larger components. (ii) To accurately detect, measure, and quantitatively analyze sugar concentration levels in milk before and after ultrafiltration to evaluate separation efficiency. (iii) To ensure careful retention of all essential milk proteins, vital nutrients, and beneficial bioactive compounds within the filtered milk, preserving its nutritional integrity. (iv) To successfully conceptualize, design, and construct a fully functional, low-cost, and easy-to-use prototype system for real-world implementation, making lactose-reduced milk accessible to small-scale dairy farmers, rural cooperatives, and households [5].

IV. Technologies used and Expected Outcomes

The project utilizes the following key technologies: (i) Conductivity sensing – using copper probes to measure electrical conductivity changes in milk caused by ionic adulterants. (ii) Transistor-based amplification – using a BC547 NPN transistor to amplify weak conductivity signals without microcontrollers. (iii) LED visual indication – providing real-time, color-coded brightness levels to indicate purity. (iv) Ultrafiltration membrane – a semipermeable membrane that selectively allows lactose molecules to pass while retaining larger proteins and nutrients. (v) Passive electronic components – including 10kΩ and 220Ω resistors for current limiting and biasing, a breadboard for assembly, and a DC power supply (5–12V) for operation. Upon successful completion, the project is expected to deliver the following outcomes: (i) A fully functional, low-cost prototype capable of detecting sugar and other ionic adulterants in raw milk within seconds. (ii) LED brightness variation that clearly distinguishes pure milk from adulterated milk (dim/bright indication). (iii) An ultrafiltration membrane setup that reduces lactose content by 60–80% while retaining over 90% of milk proteins and nutrients. (iv) A completely hardware-based, microcontroller-free, chemical-free system that is portable, battery-operated, and reusable. (v) A user-friendly design suitable for small-scale dairy farmers, households, rural cooperatives, and educational institutions. (vi) Documented test results showing sensitivity to as low as 5–10% adulteration. (vii) A scalable design that can be further enhanced with temperature compensation, digital display, IoT connectivity, and commercial manufacturing [7].

V. Literature Survey

Milk is one of the most widely consumed nutritional foods worldwide. However, the presence of excess sugar and adulterants in milk can affect its quality, nutritional value, and suitability for people suffering from diabetes, lactose intolerance, and obesity. Researchers have proposed various techniques for sugar detection and lactose reduction in milk, ranging from conventional chemical analysis to advanced sensor-based systems and membrane separation technologies. This literature survey reviews existing methods, their advantages, limitations, and identifies research gaps that motivate the present work. Conductivity-based milk adulteration detection has emerged as a simple, low-cost, and rapid technique for identifying changes in milk quality caused by the addition of external substances. Tripathy et al. (2017) investigated the use of electrical conductivity measurements for detecting adulterants in milk and showed that substances such as sugar, water, and salts alter the ionic concentration of milk, thereby producing measurable variations in conductivity [8].
These techniques are highly useful for developing milk products suitable for lactose-intolerant consumers because they effectively reduce lactose while preserving proteins and essential nutrients. However, membrane fouling, high equipment cost, maintenance requirements, and the need for careful process optimization remain major challenges for industrial-scale implementation as seen in Table 1.

TABLE I: Comparison of the Existing Technologies

Method	Principle	Advantages	Limitations
Chemical Testing	Reaction with reagents	High accuracy	Requires chemicals and laboratory setup
Conductivity Sensing	Electrical conductivity measurement	Low cost, simple design	Limited specificity
pH-Based Detection	Acidity measurement	Easy implementation	Affected by external factors
Biosensor Systems	Biological sensing elements	High sensitivity	Expensive and complex
Ultrafiltration/Diafiltration	Membrane separation	Removes lactose effectively	Membrane fouling and cost issues

VI. System Design and Methodology Adopted

The proposed system architecture consists of two major sections, namely the sugar separation unit and the sugar detection unit. The sugar separation unit is designed to remove lactose and other dissolved sugar molecules from raw milk with the help of a semipermeable membrane. This membrane works on the principle of selective separation, where smaller sugar molecules are allowed to pass through the membrane pores, while larger molecules such as proteins, fats, minerals, and other essential nutrients are retained in the milk. Thus, the membrane-based separation process helps in reducing the sugar content of milk without significantly affecting its nutritional components. This unit is especially useful for developing low-sugar or lactose-reduced milk samples and can be considered an important stage before detection and quality analysis [9]..
The hardware section of the system includes simple and easily available electronic and sensing components. The semipermeable membrane performs the main function of lactose separation by allowing smaller sugar molecules to pass through while retaining useful milk constituents such as proteins, fats, and minerals. The copper probes serve as conductivity sensing electrodes and are directly placed in the milk sample to measure electrical conductivity. The BC547 NPN transistor acts as an amplifier for the small signal obtained from the probes and helps in operating the LED indicator. The 10 kΩ resistor is used to control the base current of the transistor, while the 220 Ω resistor limits the current flowing through the LED and protects it from damage. The LED indicator provides a simple visual output showing changes in conductivity, and the 9V battery supplies power to

the complete circuit. A breadboard is used for temporary assembly, testing, and modification of the circuit before final implementation [11].

VII. CIRCUIT DIAGRAM AND FLOW CHART

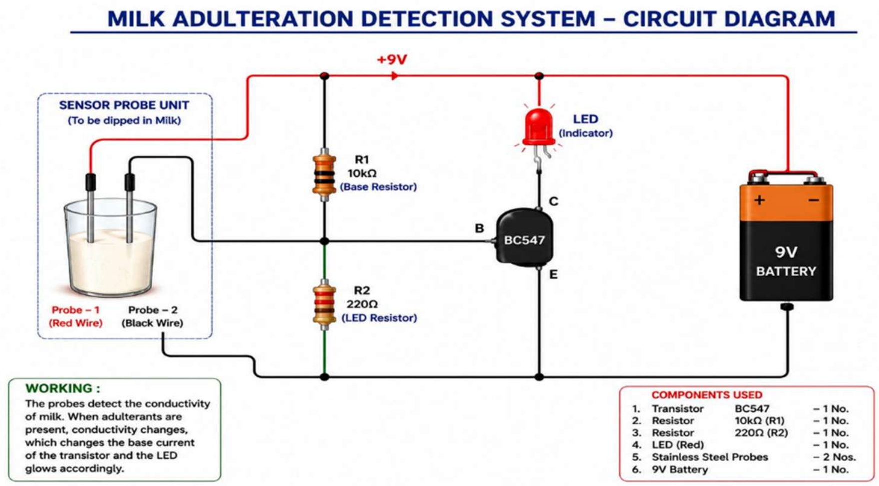

Fig. 1: Milk Adulteration Detection System Diagram

The two probes are immersed in the milk sample. Conductivity between probes creates a small base current. The BC547 transistor amplifies this current. The collector current drives the LED. LED brightness changes according to conductivity variation & the overall circuit diagram is shown in the Fig 1 along with the flow-chart in Fig. 2 [12].

VIII. WORKING METHODOLOGY AND RESULTS

The proposed system operates in two stages: sugar separation and sugar detection. Initially, raw milk is passed through a semipermeable membrane. Due to the pore size characteristics of the membrane, lactose and other small sugar molecules pass through the membrane while larger proteins and fat globules are retained. This process reduces the sugar concentration of the milk without significantly affecting its nutritional quality. After filtration, conductivity measurement is carried out using two copper probes inserted into the milk sample. Electrical conductivity depends on the concentration of dissolved ions and molecules present in the liquid. Any variation in sugar concentration causes a corresponding change in conductivity. The small electrical signal generated between the probes is applied to the base of a BC547 transistor. The transistor amplifies the signal and controls the current flowing through an LED. Depending on the conductivity level, the LED brightness changes, providing a simple visual indication of milk quality and sugar concentration. : A known volume of Fehling's solution is reduced by lactose present in the milk. The endpoint is the appearance of brick-red precipitate, indicating complete reduction of Cu^{2+} ions. Lactose content in the milk sample was determined using the Fehling's titration method. Reagent A was prepared by dissolving 2 g of lead acetate in a 10 mL volumetric flask and making up the volume with distilled water. Reagent B was prepared by dissolving 0.3 g of potassium oxalate and 0.4 g of disodium hydrogen phosphate in a 10 mL volumetric flask.A lactose standard solution was prepared by dissolving 0.75 g of lactose powder in a 250 mL volumetric flask containing 100 mL of hot distilled water. The solution was heated in a water bath at 60°C for 30 minutes, cooled to room temperature, and diluted to the mark with distilled water.For sample preparation, 15 mL of milk was transferred into a 250 mL volumetric flask and mixed with 100 mL of hot distilled water. The mixture was heated at 60°C for 30 minutes and then cooled to room temperature. To clarify the sample and remove interfering substances, 4 mL of Reagent A and 5 mL of Reagent B were added, and the mixture was allowed to stand for 10 minutes.For lactose determination, 5 mL each of Fehling's Solution A and Fehling's Solution B were mixed with 20 mL of distilled water. A few drops of methylene blue indicator were added, and the solution was titrated with both the lactose standard and prepared milk sample. The endpoint was identified by a color change from blue to brick red, indicating the reduction of copper(II) ions to cuprous oxide (Cu_2O) by lactose present in the sample.

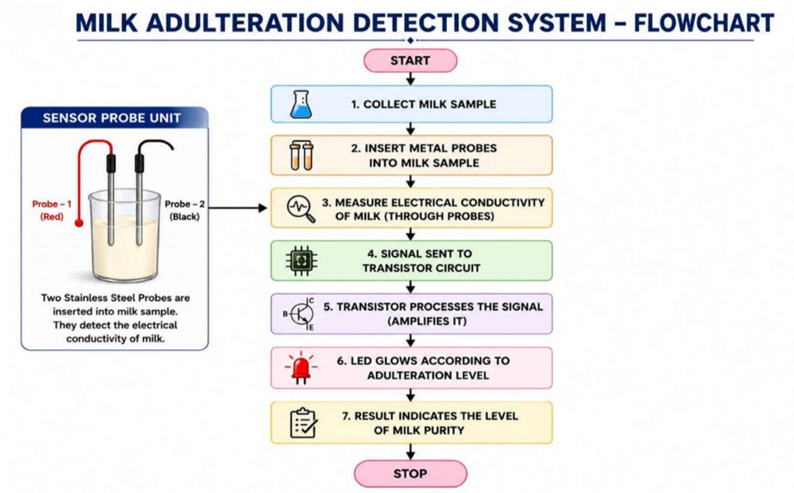

Fig. 2: Milk Adulteration Detection System Flowchart

The system is entirely hardware-based, low-cost, easy to operate, and does not require any microcontroller, programming, or complex instrumentation. This makes it suitable for educational demonstrations and small-scale milk quality monitoring applications. The proposed system was implemented using a semipermeable membrane for sugar separation and a conductivity-based electronic circuit for sugar detection.

IX. Experimental Set-Ups

Hardware Components Used - BC547 NPN Transistor, Copper Conductivity Probes, 10 kΩ Resistor, 220 Ω Resistor, LED Indicator, 9V Battery, Breadboard, Semipermeable Membrane. The system was tested using different milk samples to observe conductivity variations and LED response as seen in table 2.

Table II: Test Cases

Test Case	Expected Result	Actual Result	Status
Pure Milk	Normal LED	Observed	Pass
Filtered Milk	Reduced Brightness	Observed	Pass
Sugar-Adulterated Milk	Higher Brightness	Observed	Pass
Repeated Test	Consistent Output	Observed	Pass

- Raw milk produced a normal conductivity response.
- Filtered milk showed a reduction in conductivity due to decreased sugar concentration.
- Sugar-added milk produced higher conductivity and brighter LED indication.
- The circuit showed stable operation during repeated testing.
- The BC547 transistor successfully amplified small conductivity changes.

A. Observation Table

Table III: Standardization of Fehling's Solution

Trial	Initial burette reading (ml)	Final burette reading (ml)	Volume of lactose solution(ml)
01.	0.0	22.1	22.1

Table IV: Estimation Using Milk Sample

Trial	Initial burette reading (ml)	Final burette reading (ml)	Volume of milk filtrate (ml)
01.	0.0	22.6	22.6

The conductivity of milk changed noticeably with variation in sugar concentration. The LED brightness served as a simple visual indicator of these changes. The membrane filtration process reduced sugar concentration while maintaining the overall structure of milk as seen in the table 5.

TABLE V: RESULT ANALYSIS

Sample	LED Brightness	Conductivity	Observation
Raw Milk	High	High	Higher sugar content
After Filtration	Medium	Moderate	Reduced sugar content
Sugar Added Milk	Very High	Very High	Maximum conductivity
Diluted Milk	Low	Low	Reduced conductivity

V. DISCUSSIONS ON THE RESULTS

The experimental results confirm that conductivity can be used as a low-cost method for detecting changes in sugar concentration in milk. The membrane filtration stage successfully reduced sugar content, while the conductivity sensing circuit provided a simple method for monitoring the effectiveness of the separation process. The proposed system achieved the project objectives of sugar separation, detection, and visual indication without requiring any microcontroller or software programming. The developed prototype successfully demonstrated & implemented.

VII. CONCLUSIONS

The proposed system successfully demonstrates a simple and low-cost method for the separation and detection of sugar in raw milk. A semipermeable membrane is used to reduce sugar content while retaining essential nutrients. The conductivity-based detection circuit, consisting of copper probes, a BC547 transistor, and an LED indicator, provides a simple way to monitor changes in milk quality. The system does not require any microcontroller or programming, making it economical, easy to operate, and suitable for educational and small-scale dairy applications. Applications are - Milk quality monitoring, Adulteration detection, Dairy processing units, Educational laboratory projects, Benefits, Low cost, Simple design, Real-time indication, Easy maintenance, Portable and user-friendly.

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