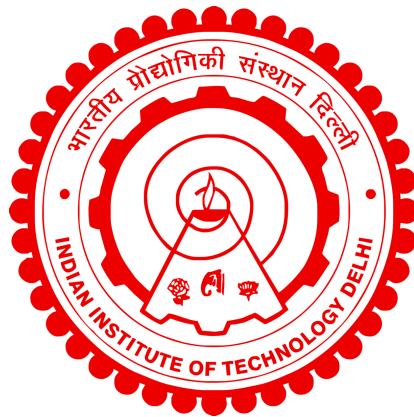


DEVELOPMENT OF SENSOR BASED PORTABLE INSTRUMENT TO TEST MILK QUALITY

AJAY KUMAR YADAV



Center for Rural Development and Technology

INDIAN INSTITUTE OF TECHNOLOGY DELHI

May 2025

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**DEVELOPMENT OF SENSOR BASED
PORTABLE INSTRUMENT TO TEST MILK
QUALITY**

by

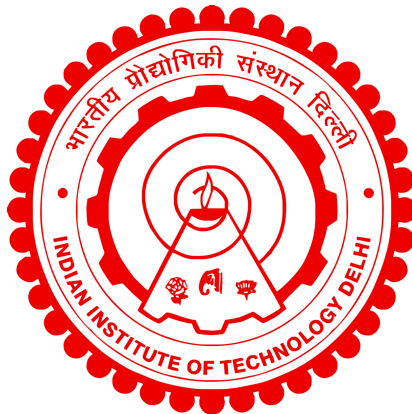
AJAY KUMAR YADAV

Center for Rural Development and Technology

Submitted

in partial fulfillment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY
DELHI**

May 2025

*In loving memory of my father, Late Shri Jayveer Singh,
and my younger brother, Late Kushal....*

Certificate

This is to certify that the thesis entitled “**Development of Sensor-based Portable Instrument to Test Milk Quality**”, submitted by **Ajay Kumar Yadav** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of the original, bonafide research work carried out by him under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

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Ajay Kumar Yadav

Abstract

Milk, a traditional and vital component of human meals, is highly valued for its nutritional content, providing crucial proteins, lipids, minerals, and vitamins. Consumers' widespread perception of milk as a wholesome food option is a significant incentive for dishonest people to adulterate the milk to maximize financial gains. Due to its high perishability, milk is susceptible to quick bacterial contamination, making raw milk unfit for processing or consumption for a long duration. Frequently, illicit utilization of chemical preservatives augments the longevity of milk and milk products, but presents significant health hazards to consumers. Possessing detection tools for identifying adulteration in milk is crucial to ensure consumer safety. Several detection technologies are available, but their widespread use is severely constrained by their high cost, complicated nature, and need for laboratory settings.

To evaluate the severity of adulteration, a risk analysis model was developed based on input from medical professionals. Each adulterant was categorised according to its health impact on consumers. Besides this, the thesis addresses the critical issue of milk adulteration by introducing an innovative, low-cost, portable sensor for detecting chemical adulterants in milk. The developed sensor operates on the principle of electrical conductivity measurement, identifying changes caused by adulterants such as sodium hydroxide, hydrogen peroxide, and water. The prototype effectively detects and quantifies adulterants' impact on milk composition by analysing impedance shifts and output voltage variations. The developed device is compact, user-friendly, and cost-effective, requiring only 4 mL of milk per test and operating on a low-power battery or USB adapter. Under laboratory conditions, the sensor demonstrated high sensitivity, detecting minimum adulteration levels of 0.5% formaldehyde, 0.2% sodium hydroxide and 0.025% sodium bicarbonate. Additionally, the prototype successfully distinguished adulteration levels up to 0.5% for sodium hydroxide and hydrogen peroxide and up to 10% for water adulteration. The findings highlight the potential of this sensor-based device as a practical first-line defense against milk adulteration, offering consumers and small-scale dairy producers an accessible and efficient milk quality assessment tool.

सारांश

दूध, मानव भोजन का एक पारंपरिक और महत्वपूर्ण घटक है, जो अपने पोषण तत्वों के लिए अत्यधिक मूल्यवान है, जो महत्वपूर्ण प्रोटीन, लिपिड, खनिज और विटामिन प्रदान करता है। उपभोक्ताओं द्वारा एक पौष्टिक भोजन विकल्प के रूप में दूध की मान्यता, बेईमान लोगों द्वारा दूध में मिलावट कर अनुचित लाभ कमाने का एक बड़ा कारक है। इसकी उच्च नाशवानता के कारण, दूध जल्दी बैक्टीरिया से दूषित होने के लिए अतिसंवेदनशील होता है, जिससे कच्चा दूध प्रसंस्करण या लंबे समय तक उपभोग के लिए अनुपयुक्त हो जाता है। अक्सर, रासायनिक परिरक्षकों का अवैध उपयोग दूध और दूध उत्पादों की दीर्घायु को बढ़ाता है, लेकिन उपभोक्ताओं के लिए महत्वपूर्ण स्वास्थ्य खतरे भी प्रस्तुत करता है। दूध में मिलावट की पहचान कर उपभोक्ता सुरक्षा सुनिश्चित करने के लिए पहचान उपकरण होना महत्वपूर्ण है। कई पहचान तकनीकें उपलब्ध हैं, लेकिन उनका व्यापक उपयोग उनकी उच्च लागत, जटिल प्रकृति और प्रयोगशाला सेटिंग्स की आवश्यकता के कारण गंभीर रूप से बाधित होता है।

इस थीसिस में मिलावट की गंभीरता का मूल्यांकन करने के लिए, चिकित्सा पेशेवरों से इनपुट के आधार पर एक जोखिम विश्लेषण मॉडल विकसित किया गया है। प्रत्येक मिलावट को उपभोक्ताओं पर उसके स्वास्थ्य प्रभाव के अनुसार वर्गीकृत किया गया है। इसके अलावा, दूध में रासायनिक मिलावट का पता लगाने के लिए एक अभिनव, कम लागत वाला, पोर्टेबल सेंसर भी प्रस्तुत किया गया है। विकसित सेंसर विद्युत चालकता माप के सिद्धांत पर काम करता है, तथा सोडियम हाइड्रॉक्साइड, हाइड्रोजन परऑक्साइड और पानी जैसे परिरक्षकों के कारण होने वाले परिवर्तनों की पहचान करता है। प्रोटोटाइप प्रतिबाधा शिफ्ट और आउटपुट वोल्टेज भिन्नताओं का विश्लेषण करके दूध की संरचना पर मिलावट के प्रभाव को प्रभावी ढंग से पहचानता है और उसकी मात्रा को मापता है। विकसित डिवाइस कॉम्पैक्ट, उपयोगकर्ता के अनुकूल और लागत प्रभावी है, जिसके लिए प्रति परीक्षण केवल 4 एमएल दूध की आवश्यकता होती है और यह कम-शक्ति वाली बैटरी या यूएसबी एडाप्टर पर काम करता है। प्रयोगशाला स्थितियों के तहत, सेंसर ने उच्च संवेदनशीलता का प्रदर्शन किया, 0.5% फॉर्मेल्डिहाइड, 0.2% सोडियम हाइड्रॉक्साइड और 0.025% सोडियम बाइकार्बोनेट के न्यूनतम मिलावट स्तरों का पता लगाया। इसके अतिरिक्त, प्रोटोटाइप ने सोडियम हाइड्रॉक्साइड और हाइड्रोजन पेरोक्साइड के लिए 0.5% तक और पानी की मिलावट के लिए 10% तक की मिलावट के स्तर को सफलतापूर्वक पहचाना। निष्कर्ष दूध में मिलावट के खिलाफ एक व्यावहारिक प्रथम-पंक्ति बचाव के रूप में इस सेंसर-आधारित डिवाइस की क्षमता को उजागर करते हैं, जो उपभोक्ताओं और छोटे पैमाने के डेयरी उत्पादकों को एक सुलभ और कुशल दूध गुणवत्ता मूल्यांकन उपकरण प्रदान करता है।

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Abbreviations

US	U nadulterated S ample
ASS	A dulterated S ample with S odium H ydroxide
ASH	A dulterated S ample with H ydrogen P eroxide
ASSB	A dulterated S ample with S odium B icarbonate
ASF	A dulterated S ample with F ormaldehyde
ASW	A dulterated S ample with W ater
DI	D ionized
ADC	A nalog to D igital C onverter
DAC	D igital to A nalog C onverter
UART	U niversal A synchronous R eceiver T ransmitter
SPI	S erial P eripheral I nterface
PWM	P ulse W idth M odulation
I2C	I nter I ntegrated C ircuit

Symbols

ϵ	dielectric constant/permittivity
ϵ_0	dielectric constant/permittivity of free space
C_p	parallel plate capacitance
Z	impedance
θ	phase angle
σ	conductivity