

System For Predicting Colony Forming Unit In Alimentary Substances

Field of invention

5 This invention relates to a method and a system that predicts bacterial density at a predetermined time. More particularly, this invention relates to calculating an estimated overall bacterial density of multiple series at the end of an incubation period. Still more particularly, this invention relates to a method and a system that
10 uses observed bacterial density of a reference series at an end of an intermediate time period to calculate an estimated overall bacterial density of multiple series at the end of the incubation period.

Background

15 In the food industry, food safety testing is conducted regularly and is an integral component of worldwide food distribution network. In particular, the testing for the contamination of food by microorganisms such as *E. coli* and *S. aureus* is regularly performed to prevent the spread of these microorganisms to consumers.

20 One commonly used test for microorganisms is the multiple-tube method, also known as the Most Probable Number (MPN) method. MPN is a common low-cost method used to enumerate bacterial density as a quality indicator. The US Food and Drug Administration (FDA) in the Bacteriological Analytical Manual (BAM) recognizes MPN as an acceptable test for such microorganisms.

25 The MPN method is typically performed in the following manner. A series of 10-fold dilutions of a sample of interest in repeated sets of tubes under a certain culture medium are prepared. The series are then incubated for a fix time period, such as 48 hours. After the incubation period, each dilution in each series is inspected for
30 observable bacteria or other microorganisms. The bacterial density is then calculated from the observable bacteria to determine whether the sample meet food safety criteria.

It is a problem with the MPN method that there is no way to make the determination of bacterial density until after the incubation period elapses. Thus, no results can be known during the incubation period. Hence, no food quality assessment can be provided during this incubation period. Due to the nature of downstream food distribution network, when food contamination is detected, it is harder to trace the source and the contaminated food that has been distributed. As time passes, it will become increasingly difficult and expensive to recall the contaminated food.

Thus, those skilled in the art are constantly striving to provide a method and a system that predicts the bacterial density as a quality indicator at an earlier stage of food distribution without increasing the cost of the testing procedure.

Summary of Invention

The above and other problems are solved and an advance in the art is provided by a method and a system that predicts the overall bacterial density at the end of an incubation period in accordance with this invention. A first advantage of a system and a method in accordance with this invention is that the prediction of the bacterial density at an earlier time allows the quality of food to be determined at an earlier stage of food distribution. This allows unacceptable products to be removed from the distribution network at a much earlier stage in the food distribution. A second advantage in accordance with this invention is that no additional materials or samples are needed. This invention can be implemented with the material and sample required for the current MPN method. Thus, a system and a method in accordance with this invention do not increase the cost of performing such tests.

A system and a method for predicting bacterial density in accordance with an embodiment of this invention is provided in the following manner. The system receives a number of tubes in each series that exhibit bacterial growth at a first incubation time and calculates a bacterial density of each of individual series from the number of tubes exhibiting bacterial growth in each of individual series at the first incubation time. The series having a highest bacterial density is determined to be a reference series. The system then calculates an estimated adjusted number of tubes that exhibit growth in each series at a second incubation time using the reference

series. An overall bacterial density of all of the series is calculated using the estimated adjusted number of tubes for each of individual series. An estimated overall bacterial density at the second incubation time is subsequently calculated from the overall bacterial density. In accordance with this embodiment, the second incubation
5 time is greater than the first incubation time.

In accordance with an embodiment of this invention, the method takes samples from a liquid and places each of the samples inoculums in a number of tubes. The tubes are arranged into multiple series and are incubated. The tubes are observed for
10 growth of organism at the end of the first incubation time. The method further includes determining a number of tubes that exhibit growth in a number of tubes in a series.

In accordance with an embodiment of this invention, the first incubation time
15 is less than the second incubation time. Preferably, the second incubation time is the time required for the bacteria population to reach maximum growth.

In accordance with an embodiment of this invention, the estimated overall bacterial density is determined based upon a type of identified organism, a culture
20 medium, or organism growth indicator.

In accordance with an embodiment of this invention, the bacterial density for each series is calculated using the following equation:

$$-\frac{1}{v} \ln \left(1 - \frac{f}{n} \right)$$

25 Wherein v is the volume of the sample inoculums in a tube of one of the series, f is the number of tubes in one of the series that exhibit growth, and n is the number of media tubes in the series.

In accordance with an embodiment of this invention, the system determines
30 one of the series that has a smaller sample inoculums volume than the sample inoculums volume of the reference series. In response to the series having a smaller sample inoculums volume than the reference series, the system calculates an estimated

adjusted number of tubes that exhibit growth at a second incubation time using the reference series and the following equation:

$$f_i^{\text{Predict}} = \arg \min f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) > \delta^{\text{ref}} \right\}$$

Wherein f_i^{Predict} is the estimated adjusted number of tubes that exhibits growth at the end of the second incubation time, v_i is the volume of the sample inoculums in the tube, f_i is the number of tubes that exhibit growth, n_i is the number of media tubes for the series, and δ^{ref} is the reference bacterial density.

In accordance with an embodiment of this invention, the system determines one of the series that has a larger sample inoculums volume than the sample inoculums volume of the reference series. In response to a determination that a series has a larger sample inoculums volume than the reference series, the system calculates an estimated adjusted number of tubes that exhibit growth at a second incubation time for the series using the reference series and the following equation:

$$f_i^{\text{Predict}} = \arg \max f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) < \delta^{\text{ref}} \right\}$$

Wherein f_i^{Predict} is the estimated adjusted number of tubes that exhibits growth at the end of the second incubation time, v_i is the volume of the sample inoculums in the tube, f_i is the number of tubes that exhibit growth, n_i is the number of media tubes for the series, and δ^{ref} is the reference bacterial density.

In accordance with an embodiment of this invention, the overall bacterial density of the plurality of series is calculated using the estimated adjusted number of tubes for each of the series using the following equation:

$$\sum_{i=1}^m (n_i - f_i) v_i = \prod_{i=1}^m \frac{f_i v_i \exp^{-v_i \delta}}{1 - \exp^{-v_i \delta}}$$

Wherein m is a number of the series, n_i is the number of media tubes for an i^{th} one of the series, f_i is the number of tubes that exhibit growth for the i^{th} one of the series, v_i

is the volume of the sample inoculums in the tube for the i^{th} one of series, and δ is the overall bacterial density to be calculated.

In accordance with an embodiment of the invention, the system calculates a total variance using the following equation:

$$v^2 = \sum \frac{(\log(Density_{\text{Predicted}}) - \log(Density_{\text{Expected}}))^2}{\log(Density_{\text{Expected}})}$$

Wherein v^2 is a normalized log variance.

Brief description of drawings

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The above and other features and advantages of a method and a system in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating a first set of dilution series for detecting bacterial growth in accordance with this invention;

Figure 2 illustrating a set of series for detecting bacterial growth in accordance with this invention;

Figure 3 illustrating a block diagram of a processing system of the various components for providing a system in accordance with an embodiment of this invention; and

Figure 4 illustrating a processing system representative of processing systems in devices that perform processes for providing a method and system in accordance with this invention.

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Detailed description

This invention relates to a method and a system that predicts bacterial density at a predetermined time. More particularly, this invention relates to calculating an estimated overall bacterial density of multiple series at the end of an incubation period. Still more particularly, this invention relates to a method and a system that uses observed bacterial density of a reference series at an end of an intermediate time

period to calculate an estimated overall bacterial density of multiple series at the end of the incubation period.

This invention can be setup using the method as shown in figures 1 or 2. As shown in figure 1, the sample inoculums with different dilution factors are placed into a number of culture media tubes to form a dilution series. Alternatively, the sample inoculums with different volume are placed into a number of culture media tubes to form a series as illustrated in figure 2. In either of the setup as shown in figure 1 or 2, the series of culture media tubes are incubated in a suitable culture medium for a period of time, and observed to detect any growth of microorganism that has taken place. More particularly, the number of tubes that exhibit growth in a series are observed. One skilled in the art will recognize that the underlying assumption is that any culture media tube that contains at least one organism will exhibit growth that is detectable at the end of the incubation period.

This invention assumes that the samples in different series of culture media tubes can take different durations of the incubation period to provide an observable bacterial growth. Therefore, at any time prior to end of the incubation period for all of the series of samples, the inconsistency of each of the series enumerated bacterial density indicates the incompleteness of bacterial incubation that is reflected by the observable bacterial growth.

Figure 3 illustrates a block diagram of the components of a processing system that executes instructions stored in a memory to provide processes in accordance with this invention. One skilled in the art will recognize that Figure 3 is for illustrative purposes only and the exact configuration of the components in the processing device may be different without departing from this invention. Processing system 300 includes Central Processing Unit (CPU) 305. CPU 305 is a processor, microprocessor, or any combination of processors and microprocessors that execute instructions to perform the processes in accordance with the present invention. CPU 305 connects to memory bus 310 and Input/Output (I/O) bus 315. Memory bus 310 connects CPU 305 to memories 320 and 325 to transmit data and instructions between the memories and CPU 305. I/O bus 315 connects CPU 305 to peripheral devices to transmit data between CPU 305 and the peripheral devices. One skilled in the art will

recognize that I/O bus 315 and memory bus 310 may be combined into one bus or subdivided into many other busses and the exact configuration is left to those skilled in the art.

5 A non-volatile memory 320, such as a Read Only Memory (ROM), is connected to memory bus 310. Non-volatile memory 320 stores instructions and data needed to operate various sub-systems of processing system 300 and to boot the system at start-up. One skilled in the art will recognize that any number of types of memory may be used to perform this function.

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 A volatile memory 325, such as Random Access Memory (RAM), is also connected to memory bus 310. Volatile memory 325 stores the instructions and data needed by CPU 305 to perform software instructions for processes such as the processes for providing a system in accordance with this invention. One skilled in the
15 art will recognize that any number of types of memory may be used to provide volatile memory and the exact type used is left as a design choice to those skilled in the art.

 I/O device 330, keyboard 335, display 340, memory 345, network device 350 and any number of other peripheral devices connect to I/O bus 315 to exchange data
20 with CPU 305 for use in applications being executed by CPU 305. I/O device 330 is any device that transmits and/or receives data from CPU 305. Keyboard 335 is a specific type of I/O that receives user input and transmits the input to CPU 305. Display 340 receives display data from CPU 305 and display images on a screen for a user to see. Memory 345 is a device that transmits and receives data to and from CPU
25 305 for storing data to a media. Network device 350 connects CPU 305 to a network for transmission of data to and from other processing systems.

 Figure 4 illustrates an embodiment of a process for estimating an overall bacterial density of test series in accordance with this invention. Process 400 begins
30 with step 405. In step 405, the system receives a number of tubes in each of series that exhibit bacterial growth at a first incubation time. In step 410, the system calculates a bacterial density of each of the series from the number of tubes exhibiting bacterial growth in each of the series at the first incubation time. The bacterial density for each of the series in step 410 is calculated using the following equation:

$$-\frac{1}{v} \ln \left(1 - \frac{f}{n} \right) \quad (\text{Equation 1})$$

Wherein v is the volume of the sample inoculums in a tube of one of the series, f is the number of tubes in one of the series that exhibit growth, and n is the number of media tubes for one of the series.

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The series having a highest bacterial density is determined to be a reference series in step 415. Subsequently, the system calculates an estimated adjusted number of tubes that exhibit growth in each of the series at a second incubation time using the reference series in step 420. The second incubation time is typically the time required for the bacteria population to reach maximum growth and the first incubation time is typically half the time of the second incubation time. One skilled in the art will recognize that the second incubation time period is greater than the first incubation time period and the choice of the exact incubation period of both first and second incubation time period is left to one skilled in the art. More particularly in step 420, the observable bacterial growth for the series other than the reference series are adjusted based on the reference bacterial density to reflect the bacterial density for these series that exhibit slower observable bacteria growth. As the volume of sample inoculums in the series varies, it is possible that volume of sample inoculums in some of the series may either be smaller or larger than the reference series. Hence, the system compares the volume of sample inoculums between each one of the remaining series and the reference series and determines if each particular series is smaller or larger than the volume of sample inoculums in the reference series.

If the volume of sample inoculums of a particular series is smaller than the reference series, the system calculates an estimated adjusted number of tubes that exhibit growth in the series at the end of the second incubation time using the reference series and the following equation:

$$f_i^{\text{Predict}} = \arg \min f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) > \delta^{\text{ref}} \right\} \quad (\text{Equation 2})$$

Wherein f_i^{Predict} is the estimated adjusted number of tubes that exhibits growth at the end of the second incubation time, v_i is the volume of the sample inoculums in the

tube, f_i is the number of tubes that exhibit growth, n_i is the number of tubes for the series, and δ^{ref} is the reference bacterial density. Equation 2 is used to calculate an independent bacterial density which is not more than that of the reference series. This is because each series with a lower volume of the sample inoculums in the tube provides for a larger range of enumerated density and hence has a lower accuracy.

If the volume of sample inoculums of the particular series is larger than the reference series, the system calculates an estimated adjusted number of tubes that exhibit growth for the series at the end of the second incubation time using the reference series and the following equation:

$$f_i^{Predict} = \arg \max f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) < \delta^{ref} \right\} \quad (\text{Equation 3})$$

Wherein $f_i^{Predict}$ is the estimated adjusted number of tubes that exhibits growth at the end of the second incubation time, v_i is the volume of the sample inoculums in the tube, f_i is the number of tubes that exhibit growth, n_i is the number of tubes for the series, and δ^{ref} is the reference bacterial density. Equation 3 is to calculate an independent bacterial density which is slightly more than that of the reference series. This is because the series with a larger volume of the sample inoculums in the tube provides for a smaller range of enumerated density and hence has a higher accuracy.

In step 425, an overall bacterial density of the series is calculated using the estimated adjusted number of tubes for each of the series. In particular, the overall bacterial density of the series is calculated using the estimated adjusted number of tubes for each of the series using the following equation:

$$\sum_{i=1}^m (n_i - f_i) v_i = \prod_{i=1}^m \frac{f_i v_i \exp^{-v_i \delta}}{1 - \exp^{-v_i \delta}} \quad (\text{Equation 4})$$

Wherein m is a number of the series, n_i is the number of tubes for an i^{th} one of the series, f_i is the number of tubes that exhibit growth for the i^{th} one of the series, v_i is the volume of the sample inoculums in the tube for the i^{th} one of the series, and δ is the overall bacterial density to be calculated.

In step 430, an estimated overall bacterial density at the second incubation time is subsequently calculated wherein the second incubation time is greater than the first incubation time. In particular, the estimated overall bacterial density is determined based upon a type of identified organism, a culture medium, or organism growth indicator using the following equation:

$$\delta \ln(t_1) / \ln(t_0)$$

Wherein δ is the overall bacterial density, t_1 is the second incubation time required based on the identified organism's growth rate, the culture medium used and the organism growth indicator used, and t_0 is the first incubation time.

As there is no direct method to calculate the accuracy of the estimated bacterial density because the estimated bacterial density is a continuous value, a total variance from the expected density is obtained as a comparison measurement for the accuracy of the predicted results. In step 435, the system calculates a total variance using the following equation:

$$v^2 = \sum \frac{(\log(Density_{Predicted}) - \log(Density_{Expected}))^2}{\log(Density_{Expected})} \quad (\text{Equation 5})$$

Wherein v^2 is a normalized log variance. Process 400 then ends.

The above is a description of embodiments of a system in accordance with the invention as set forth below. It is envisioned that those skilled in the art can and will design alternative embodiments of this invention based upon this invention that infringe on this invention as set forth in the following claims.

Claims

1. A method of predicting overall bacterial density of a plurality of series at a predetermined time comprising:
 - 5 receiving a number of tubes in each of a plurality of series that exhibit bacterial growth at a first incubation time;
calculating a bacterial density of each of said plurality of series from said number of tubes exhibiting bacterial growth in each of said plurality of series at said first incubation time;
 - 10 determining one of said plurality of series having a highest bacterial density as a reference series;
calculating an estimated adjusted number of tubes that exhibit growth at a second incubation time using said reference series; and
calculating an overall bacterial density of said plurality of series using said
15 estimated adjusted number of tubes for each of said plurality of series; and
determining an estimated overall bacterial density at said second incubation time wherein said second incubation time is greater than said first incubation time.
- 20 2. The method of claim 1 further comprising:
determining a number of tubes that exhibit growth in a total number of tubes in each of a plurality of series.
3. The method of claim 2 further comprising:
 - 25 taking a plurality of samples from a liquid;
placing each of said plurality of samples in each of said number of tubes in each of said plurality of series;
incubating said plurality of series; and
observing for growth of organism in said number of tubes.
- 30 4. The method of claim 1 wherein said second incubation time is the time required for the bacteria population to reach maximum growth.

5. The method of claim 4 wherein said first incubation time is less than the said second incubation time.

6. The method of claim 1 wherein said determining said estimated overall bacterial density is based upon a type of identified organism.

7. The method of claim 1 wherein said determining said estimated overall bacterial density is based upon a culture medium.

8. The method of claim 1 wherein said determining said estimated overall bacterial density is based upon organism growth indicator.

9. The method of claim 1 wherein said calculating bacterial density for each of said plurality of series is performed using the following equation: $-\frac{1}{v} \ln\left(1 - \frac{f}{n}\right)$,

wherein v is a volume of a sample inoculums in a tube of said one of said plurality of series, f is said number of tubes in said one of said plurality of series that exhibit growth, and n is said number of tubes for said one of said plurality of series.

10. The method of claim 1 further comprising:
determining one of said plurality of series that has a smaller sample inoculums volume than said sample inoculums volume of said reference series.

11. The method of claim 10 wherein said calculating said estimated adjusted number of tubes for said one of said plurality of series that exhibit growth at an end of said second incubation time using said reference series is performed in response to said one of said plurality of series having a smaller sample inoculums volume than said reference series using the following equation:

$$f_i^{\text{Predict}} = \arg \min f_i \left\{ -\frac{1}{v_i} \ln\left(1 - \frac{f_i}{n_i}\right) > \delta^{\text{ref}} \right\}, \text{ wherein } f_i^{\text{Predict}} \text{ is said estimated adjusted}$$

of tubes that exhibits growth at said end of said second incubation time, v_i is a volume of a sample inoculums in said tube, f_i is said number of tubes that exhibit

growth, n_i is said number of tubes for said series, and δ^{ref} is said reference bacterial density.

12. The method of claim 1 further comprises:

- 5 determining one of said plurality of series that has a larger sample inoculums volume than said sample inoculums volume of said reference series.

13. The method of claim 12 wherein said calculating said estimated adjusted number of tubes for said one of said plurality of series that exhibit growth at an end of incubation time using said reference series is performed in response to said one of said plurality of series having a larger sample inoculums volume than said reference series

10 using the following equation: $f_i^{Predict} = \arg \max f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) < \delta^{ref} \right\}$, wherein

$f_i^{Predict}$ is said estimated adjusted number of tubes that exhibits growth at said end of said second incubation time, v_i is a volume of a sample inoculums in said tube, f_i is said number of tubes that exhibit growth, n_i is said number of tubes for said series, and δ^{ref} is said reference bacterial density.

14. The method of claim 1 wherein said calculating said overall bacterial density of said plurality of series using said estimated adjusted number of tubes for each of said plurality of series is performed using the following equation:

$$\sum_{i=1}^m (n_i - f_i) v_i = \prod_{i=1}^m \frac{f_i v_i \exp^{-v_i \delta}}{1 - \exp^{-v_i \delta}}$$

, wherein m is a number of said series, n_i is said number of tubes for an i^{th} one of said plurality of series, f_i is said number of tubes that exhibit growth for said i^{th} one of said plurality of series, v_i is a volume of a sample inoculums in said tube for said i^{th} one of said plurality of series, and δ is said overall bacterial density to be calculated.

15. The method of claim 1 further comprising:

calculating a total variance using the following equation:

$$v^2 = \sum \frac{(\log(Density_{Predicted}) - \log(Density_{Expected}))^2}{\log(Density_{Expected})}$$

wherein v^2 is a normalized log variance.

- 5 16. A system for estimating an overall bacterial density of plurality of series at a predetermined time comprising:

circuitry in a quality of food controller configured to receive a number of tubes in each of a plurality of series that exhibit bacterial growth at a first incubation time,

- 10 circuitry in said quality of food controller configured to calculate a bacterial density of each of said plurality of series from said number of tubes exhibiting bacterial growth at said first incubation time,

circuitry in said quality of food controller configured to determine one of said plurality of series having a highest bacterial density as a reference series,

- 15 circuitry in said quality of food controller configured to calculate an estimated adjusted number of tubes that exhibit growth at a second incubation time using said reference series,

circuitry in said quality of food controller configured to calculate an overall bacterial density of said plurality of series using said estimated adjusted number of tubes for each of said plurality of series, and

- 20 circuitry in said quality of food controller configured to determine an estimated overall bacterial density at said second incubation time wherein said second incubation time is greater than said first incubation time.

- 25 17. The system of claim 16 wherein said second incubation time is the time required for the bacteria population to reach maximum growth.

18. The system of claim 17 wherein said first incubation time is less than the said second incubation time.

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19. The system of claim 16 wherein circuitry in said quality of food controller configured to determine said estimated overall bacterial density is based upon a type of identified organism.
- 5 20. The system of claim 16 wherein said circuitry in said quality of food controller configured to determine said estimated overall bacterial density is based upon a culture medium.
- 10 21. The system of claim 16 wherein said circuitry in said quality of food controller configured to determine said estimated overall bacterial density is based upon organism growth indicator.
22. The system of claim 16 wherein said circuitry in said quality of food controller configured to calculate bacterial density for each of said plurality of series is
- 15 performed using the following equation: $-\frac{1}{v} \ln \left(1 - \frac{f}{n} \right)$, wherein v is a volume of a sample inoculums in a tube of said one of said plurality of series, f is said number of tubes in said one of said plurality of series that exhibit growth, and n is said number of tubes for said one of said plurality of series.
- 20 23. The system of claim 16 further comprising:
circuitry in said quality of food controller configured to determine one of said plurality of series that has a smaller sample inoculums volume than said sample inoculums volume of said reference series.
- 25 24. The system of claim 23 wherein said circuitry in said quality of food controller configured to calculate said estimated adjusted number of tubes for said one of said plurality of series that exhibit growth at an end of said second incubation time using said reference series is performed in response to said one of said plurality of series having a smaller sample inoculums volume than said reference series
- 30 using the following equation: $f_i^{\text{Predict}} = \arg \min f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) > \delta^{\text{ref}} \right\}$, wherein f_i^{Predict} is said estimated adjusted of tubes that exhibits growth at said end of said

second incubation time, v_i is a volume of a sample inoculums in said tube, f_i is said number of tubes that exhibit growth, n_i is said number of tubes for said series, and δ^{ref} is said reference bacterial density.

5 25. The system of claim 16 further comprises:

circuitry in said quality of food controller configured to determine one of said plurality of series that has a larger sample inoculums volume than said sample inoculums volume of said reference series.

10 26. The system of claim 25 wherein said circuitry in said quality of food controller configured to calculate said estimated adjusted number of tubes for said one of said plurality of series that exhibit growth at an end of said second incubation time using said reference series is performed in response to said one of said plurality of series having a larger sample inoculums volume than said reference series using the

15 following equation: $f_i^{Predict} = \arg \max f_i \left\{ -\frac{1}{v_i} \ln \left(1 - \frac{f_i}{n_i} \right) < \delta^{ref} \right\}$, wherein $f_i^{Predict}$ is

said estimated adjusted number of tubes that exhibits growth at said end of said second incubation time, v_i is a volume of a sample inoculums in said tube, f_i is said number of tubes that exhibit growth, n_i is said number of tubes for said series, and δ^{ref} is said reference bacterial density.

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27. The system of claim 16 wherein said circuitry in said quality of food controller configured to calculate said overall bacterial density of said plurality of series using said estimated adjusted number of tubes for each of said plurality of series is

$$\sum_{i=1}^m (n_i - f_i) v_i = \prod_{i=1}^m \frac{f_i v_i \exp^{-v_i \delta}}{1 - \exp^{-v_i \delta}}$$

performed using the following equation: , wherein m is

25 a number of said series, n_i is said number of tubes for an i^{th} one of said plurality of series, f_i is said number of tubes that exhibit growth for said i^{th} one of said plurality of series, v_i is a volume of a sample inoculums in said tube for said i^{th} one of said plurality of series, and δ is said overall bacterial density to be calculated.

28. The system of claim 16 further comprising:
circuitry in said quality of food controller configured to calculate a total
variance using the following equation:

$$v^2 = \sum \frac{(\log(Density_{Predicted}) - \log(Density_{Expected}))^2}{\log(Density_{Expected})}$$

- 5 wherein v^2 is a normalized log variance.