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Development of a gamma ray based liquid level sensor for detecting level of liquid inside an opaque container for industrial applications

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Abstract:

Gamma based level sensor is an equipment to account for the amount of fire extinguishing liquid inside a fire extinguisher by detecting liquid level. It is useful at various places where maintenance of fire extinguishers is essentially required.Theprinciple used in this equipment is linear attenuation coefficient of liquid and gas for gamma ray. Major components in this device are a gamma source, a gamma detector and microcontroller based electronic circuit. When gamma rays pass through fire extinguisher cylinder, it has different attenuation for liquid filled part and empty part of cylinder. This device uses this difference in gamma attenuation for liquid filled part and empty part of cylinder to detect level of extinguisher liquid while scanning from bottom to top. This device has two modes of operation i.e. Calibration and Detection. Calibration mode used to calibrate device for specific diameter of cylinder. After a single calibration, this device can be used to detect liquid level of any number of cylinders of same dimension. This device has to be recalibrated for different dimension of cylinder. Detection mode is used to detect level of extinguisher liquid in cylinders. This tool simplifies the accounting of extinguishing liquid amount in fire extinguisher compared to pneumatic sensor or weighing method of cylinder as the device is light weight and it didn’t required cylinder to be lifted or shifted from their place.

Keywords: Fire extinguisher, level sensor, gamma rays, microcontroller, attenuation coefficient.

Introduction:

As per the guidelines of Bureau of Indian standards, it is mandatory to install and maintain fire extinguishers for protection of building structure as well as occupancy hazard contained therein[1]. Installation of fire extinguisher involves selection of suitable fire extinguisher and its location in the building. Installation is generally one time process but maintenance requires periodic inspection which involves fullness determination by weighing and/or other processes. This is a time consuming and cumbersome methodwhich might not be properly followed. Other methods namely capacitance level sensors, microwave level sensorsmagnetostrictive ormagnetoresistive level sensors require installation of deviceson the cylinder for testing liquid levels.

This paper discusses design and development of a gamma radiation based level sensor for quickly checking fullness of CO_2fire extinguishers. The device is based on difference of gamma attenuation between liquid and gaseous state of fire extinguisher.

Theory

As per Lambert-Beer's law [2], attenuation of photons when transmitted through a matter can be evaluated by means of linear attenuation coefficient and mass attenuation coefficient.

$$I = I_0 . e^{-\mu_l . x} \tag{1}$$

Where μ_l is linear attenuation coefficient, x is the thickness of material and I_0 is radiation intensity without attenuation between source and detector.

Mass attenuation coefficient depends on energy of interacting photons and composition of material. Linear attenuation coefficient is equal to mass attenuation coefficient multiplied by density of material. This is mathematically expressed in equation (2).

$$I = I_0 . e^{-\mu_m . x} e^{-\rho} \tag{2}$$

Where ρ is the density, $\mu_m$is mass attenuation coefficient.

I_0 is a probabilistic event which follows Normal distribution.In the above equation, μ_m is same for liquefied CO_2 and gaseous CO_2. Thickness of cylinder is constant. I_0 and density are the variablesdue to statistical fluctuation and phase of CO_2 respectively. For accurate detection of liquid-gas interface, it is required that attenuation due to liquefied CO_2 and gaseous CO_2 is distinct as shown in figure (1) and expressed in equation (3)

$$I_0 . e^{-\rho_l} \neq I_0 . e^{\rho_g} \tag{3}$$

Where ρ_l is density of liquid CO_2 and ρ_g is density of gaseous CO_2.

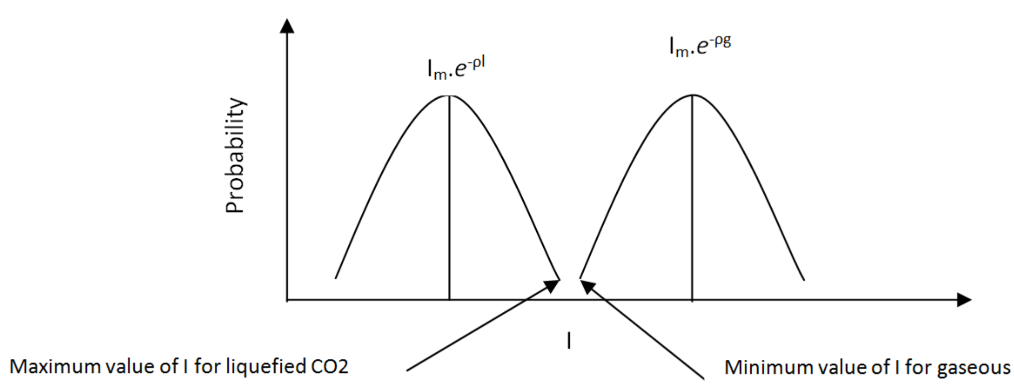


Figure 1: Probability distribution for gamma ray

In figure (1), I_m is the mean value of initial intensity. I is the intensity after attenuation. From figure (1), minimum CPS transmitted through gaseous CO_2 should be greater than maximum CPS transmitted through liquefied $CO_2$for clear discrimination between two phases of CO_2.

In statistics, 99.73% of statistical fluctuation from mean value lies in three sigma variation where sigma is standard deviation.In mathematical notation, this fact is expressed in equation (4),

$$P(\mu - 3\sigma \leq x \leq \mu + 3\sigma) \approx 0.9973 \tag{4}$$

where x is an observation from a normally distributed random variable, μ is the mean of the distribution, and σ is its standard deviation.

From equation (3) and (4), we get

$$e^{\rho_g}\mu - 3e^{\rho_g}\sqrt{\mu} = e^{\rho_l}\mu + 3e^{\rho_l}\sqrt{\mu} \tag{5}$$

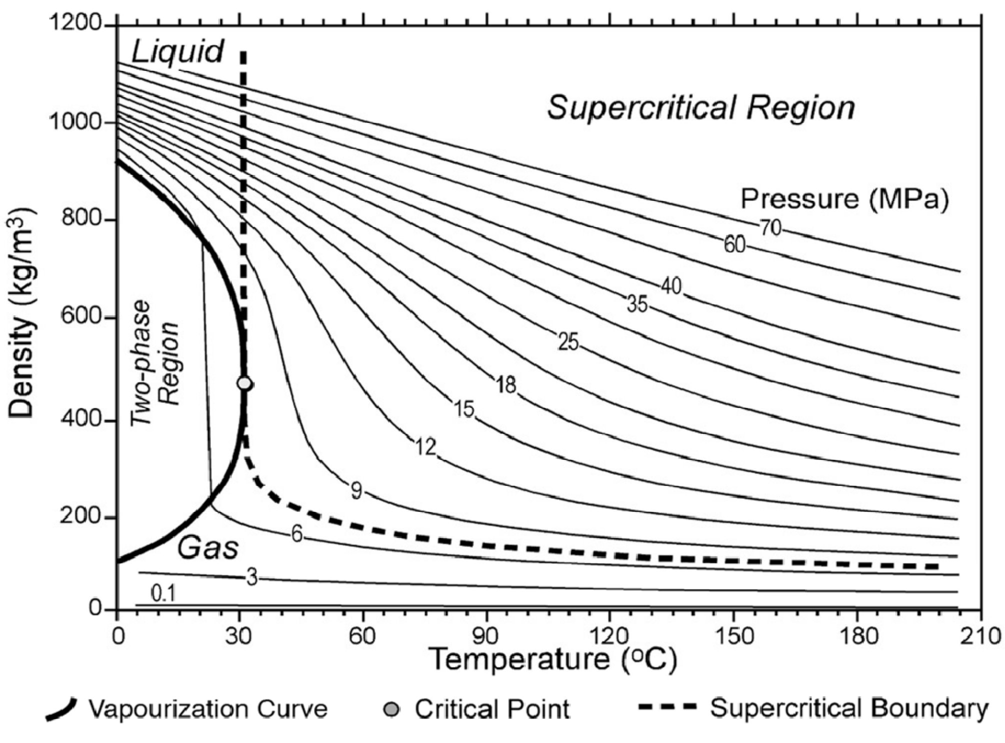


Figure2. Variation of CO2 density as a function of temperature and pressure [3]

Figure (2) gives density of CO_2at different temperature and pressure levels. In general, the pressure inside a completely filled CO_2 based fire extinguisher pressure varies from 5700KPa to 5900 KPa at 20^0C depending upon the size and material of container.

From figure (2), for aforesaid temperature and pressure range CO_2occurs in two phase i.e. Liquid phase and gaseous phase. The density of liquid CO_2 and gaseous $CO_2$is approximately 0.799 g/$cm^3$and 0.174g/cm^3respectively.Using equation(5),

$$0.84X\mu - 3X0.84X\sqrt{\mu} > 0.45X\mu + 3X0.45X\sqrt{\mu} \quad (6)$$

Solving this equation we get,

$$\mu = 96.9059 \quad (7)$$

Therefore,mean value of I_0 should begreater than or equal to 100 approximately.

From equation (4), it can be stated with 99.73% confidence that readings greater than three sigma in addition to mean value is gaseous CO_2. Therefore,the threshold is set to be thrice of standard deviation in addition to mean for reasonable detection of liquid-gas interface.

Design and development:

Hardware:

Block diagram and actual device of the system is shown in figure (3) and (4) respectively.This gamma ray based level sensor includes Co^{60} radioisotope as a gamma source. A Geiger Muller tube is used as detector.A discriminator has been applied to convert the GM signal to TTL pulses. These TTL pulses are then fed to microcontroller based unit. Microcontroller reads these TTL pulse and performscomparison with a pre calibrated threshold.

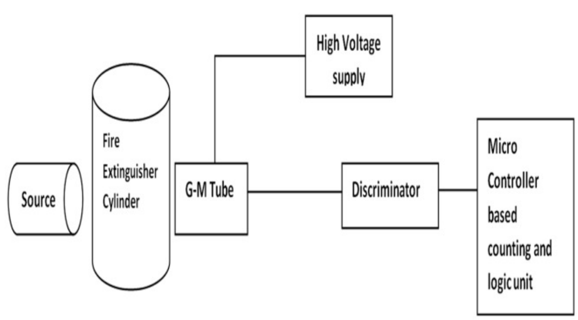


Figure 3. Block diagram of level sensor

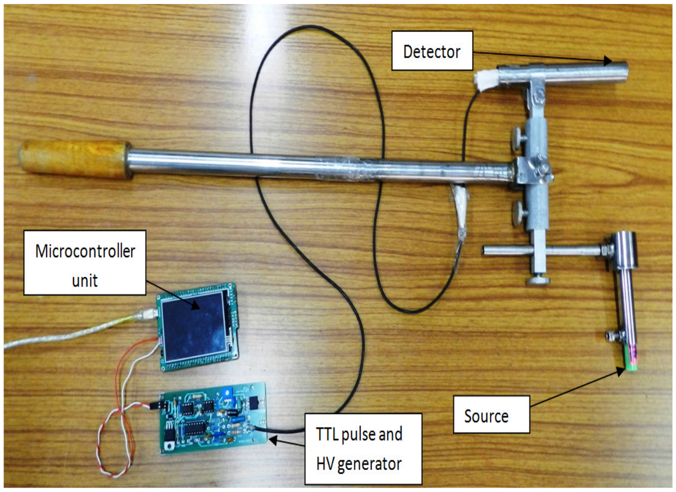


Figure 4: Level Sensor

Software:

Microcontroller based software has been developed for calibration and in situ operation of the device.

Calibration is done for a particular diameter of fire extinguisher cylinder. For a sample, the device measures radiation intensity by counting number of TTL pulses transmitted through liquefied CO_2 for 1 second. 10 such events are taken. Mean value, standard deviation and threshold isautomatically calculated. Time of sampling, increased in a step of 1000 ms, maximum to 5 seconds, is so selected that it will give at least 100 counts. If 100 counts are not available for a sampling time of 5 secondsthen anerror message "Low Activity" is returned.

During operation, as per standard operating procedure, a fire extinguisher cylinderis scanning from bottom to top.At liquid-gas interface, whenthe counts increased beyondμ +3σ, a buzzer and visual signal is generated indicating liquid level.

Experimental validation: Experimental setup is as shown in figure (5). Co^{60} source of 18.5 MBqis used in the experiment. Diameter of cylinder is 10 cm. Extinguisher material is liquid CO_2. Calibration of device is given in graph 1 and testing data is given in graph 2.

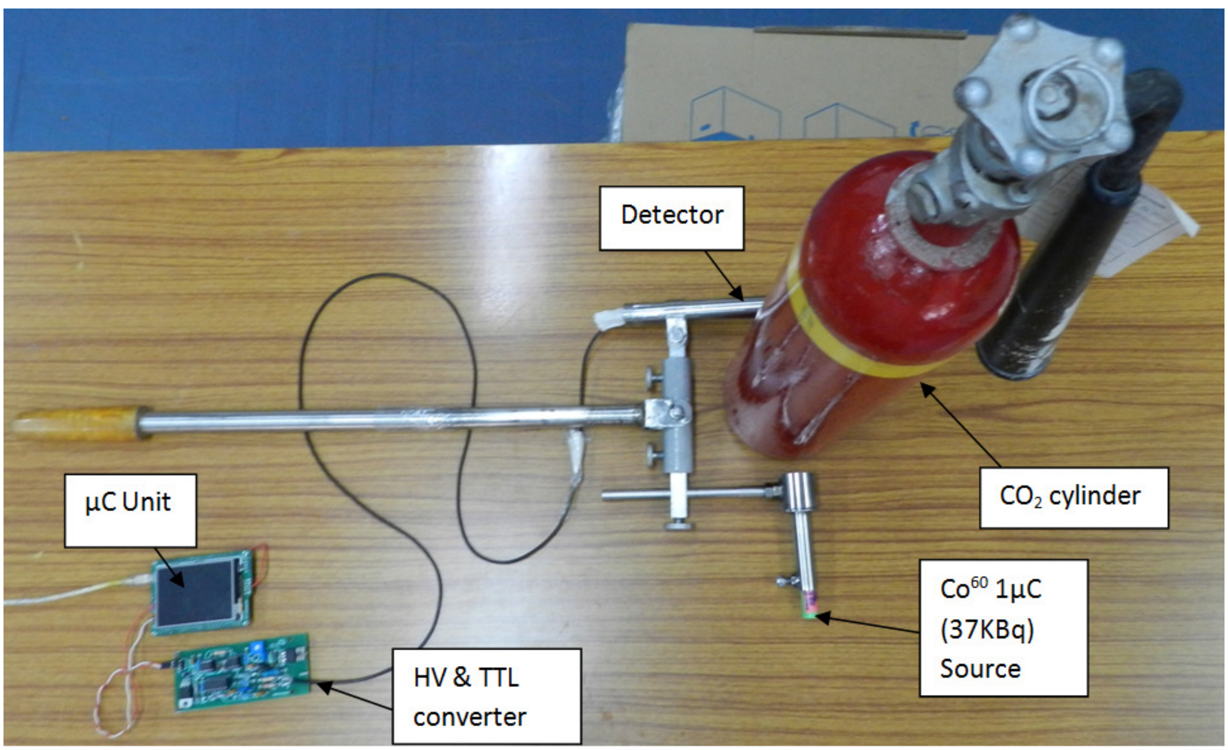
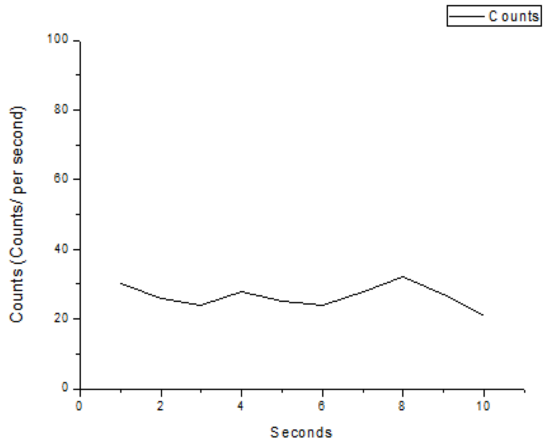
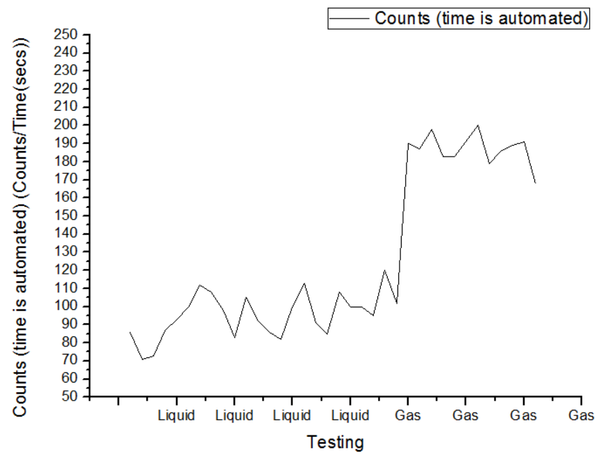


Figure 5: Experimental Setup



Graph 1: Calibration graph



Graph 2: Testing Graph

Result: Graph (1) shows the calibration. Mean value TTL pulses is 26. Sampling time is automatically calculated to 4 seconds. Threshold is set to 135 counts in 4 seconds.

Graph (2) shows the difference in attenuation is twice between liquefied and gaseous CO_2. Radiation intensity after attenuation from gaseous CO_2 roughly lies in the range of 170 to 200. Using this device liquid level can be easily detected.

Conclusion:A gamma radiation based level sensor has been built and evaluated. All software modules have been tested to be fully functional. Average value and standard deviation calculated by the system has been verified. The device has been successfully tested for five CO_2based fire extinguishers.

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