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Non-Invasive measurer for methane and carbone dioxide emissions in bovine cattle through TRIZ

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Abstract. Greenhouse gases (GHG), mainly methane (CH_4) and carbon dioxide (CO_2), can be generated in agricultural activities, not only in waste but also in the process of breathing of livestock. The Theory of Inventive Problem Solving (TRIZ) is an innovative Russian methodology that allows finding the solution to a problem raised. This paper presents the use of two TRIZ tools to design a non-invasive prototype that detects CH_4 and CO_2 emitted by cattle in real time. The tools were the matrix of technical contradictions and the nine-screen analysis with which the parameter to be improved (A) was found and the best possible solution to design a prototype that allows quantifying gases for animal welfare, Final Ideal Result (IFR) a wireless module with a sensor system for each of the gases placed on the bovine head, which convert the detected gas into an electrical signal to be sent wirelessly to a range of 1.5 km in free space at a receiver for its visualization representing the parts per million (ppm) of CH_4 and CO_2 that the bovine is generating during the measurement.

Key words: cattle, CH_4, CO_2, TRIZ.

INTRODUCTION

Methane (CH_4) is the greenhouse gas (GHG) that has the second greatest effect on climate, after carbon dioxide (CO_2). The concentration of CH_4 in the atmosphere has almost tripled in the last 150 years. Atmospheric CH_4 has a greenhouse effect at least 20 times more potent than CO_2. Agriculture, especially animal production, is one of the most important factors influencing greenhouse gases in the atmosphere and causing global warming (Dubeňová et al., 2014).

Livestock is responsible for about 23% of global CH_4 emissions of anthropogenic origin. As there is a need to quantify the amount of GHG emitted by technologies that still consume fossil fuels or GHG generated by aspects such as livestock, several quantifying devices have been designed (Álvarez-Torres et al., 2014).

Latati et al. (2019), has analyzed the phenomenon of Carbon (C) and nitrogen (N) sequestration in plants and soil micro-organisms considered as a major phenomenon against global warming, in his study is highlighted the role that the mixed crop legumes-cereals have in the reduction of greenhouse gases.

Without proper resolution, system performance is hindered, or suboptimal technologies are chosen. The Theory of Inventive Problem Solving (TRIZ), offers tools and methods to identify and resolve tradeoffs (which it terms contradictions or conflicts). TRIZ recognizes that fundamental performance limits arise when one or more unresolved tradeoffs exist in a system. According to TRIZ, eliminating or reducing the effects of the conflicts is necessary to move to improved system performance. It is here that lies the importance of the use of TRIZ as an element of integration in various environments and in the creation of new products (Blackburn et al., 2012).

Agricultural activities are the third cause of generation of GHG emissions with a contribution of 12% to national emissions, where most of the emissions are generated by enteric fermentation, manure management and by the use of fertilizers in the soils (Santillán et al., 2016).

The main biotic factor at the rumen level in the production of CH_4 are methanogenic anaerobic bacteria. CH_4 is generated by ruminal fermentation of food and surplus hydrogen (H_2) (Beltrán-Santoyo et al., 2016). Ruminants are contributing to global warming and deterioration of the ozone layer by releasing high amounts of gases into the atmosphere, including carbon dioxide and CH_4 (Carmona et al., 2005).

The recognition of generic types of problems in innovation was the key to developing TRIZ, this theory uses the systemic approach based on knowledge to achieve innovation (Acosta-Flores, 2010). TRIZ was developed to support engineers and natural scientists solving inventive problems by using the knowledge of former inventors (Moehrle, 2005).

The 40 principles of technological innovation and the 39 parameters of contradiction are the most important contribution of TRIZ and these in turn are the basis of the ‘Matrix of contradictions’. The 40 principles are generic suggestions for carrying out a specific action, within a technological system, in order to eliminate some technical contradiction (Altshuller, 2006).

The Matrix is made up of 39 parameters of contradiction and 40 principles, these inventive principles were developed when studying more than 200 thousand patents with which it was concluded that only 40 thousand had some inventive solutions, the rest were only direct improvements. Most of the problems analyzed had been solved by applying only forty fundamental principles known as ‘principles of inventiveness’ (Cordova Ames, 2008).

TRIZ is a balanced approach combining, in the same environment, psychological and technical creativity, is based on essential areas such as: statistical analysis of patents, a synthesis of the main advantages drawn from numerous problem solving techniques and an analysis of the inventor's creative thinking patterns, with the aim of producing a set of strategies for modeling and solving problems (Cortes Robles et al., 2011).

The ability to creatively solve problems has been considered a powerful tool for people and the source of innovation. However, the way of thinking creatively in solving problems, especially in technological fields such as livestock, as proposed by TRIZ, has been difficult to explain, teach and train because the ways of thinking are not well structured (Nakagawa, 2011).

Within the tools of the TRIZ, is the multiscreen analysis where time and space were established as the variables to follow, in the horizontal plane time and in the vertical plane space. For nine-screen analysis space was the system and its assemblies, the super system and subsystems. On the other hand, time considered it as the present, past and future (Bukhman, 2012).

Another tool proposed in TRIZ is the Field-Substance analysis, in which, to define a technical system, it is necessary to define two substances and one field, and that there are four basic models of technological systems: an incomplete system that requires completed to a new system; a complete but ineffective system that demands improvements to create the desired effect; a complete harmful system which is necessary to eliminate the negative effect and; an effective complete system, it is there that, for the purposes of this study, it is proposed to work with TRIZ tools to design a non-invasive and low cost CH_4 and CO_2 measurer (Acosta-Flores, 2010).

The animal welfare issues faced by the northern Australian beef cattle industry are similar to those faced by extensive livestock production industries in other countries that means that the industry faces significant challenges to assure high standards of animal welfare produced for the frequency of handling, surgical procedures, identification, transportation, including live export and others (Petherick, 2005).

In the northern of Veracruz, Mexico, one of the main activities is cattle ranching, which is why there is an interest in measuring CH_4 and CO_2 emissions. The objective of this research is to design a prototype of measurer of these GHGs in bovine cattle which is non-invasive, aiming the animal welfare.

MATERIALS AND METHODS

With the purposes to design of the prototype, a five years old cow representative female bovine of the European Swiss breed, weighing 480 kg, was taken from ranch from the municipality of Chontla in the north of the state, located between 21° 11' and 21° 40' north latitude; the meridians 97° 52' and 98° 05' west longitude; altitude between 30 and 1,300 m.

For the design of the model, 9 windows or multi-screen analysis (Table 1) and later the matrix of technical contradictions (Table 1) were used for the selection of parameters that determined the factors to be used for the prototype.

Table 1. Multiscreen analysis for the proposed measurement system

	Past	Present		Future
Super-System Level	*Field	**Laboratory	***Field	Field
System Level	Methane meter	Breathing chamber	Electronic measuring module for telemetry	Non-invasive Real-Time Measurement System
Subsystem level	Cannula, valve, collection bags, tubes	Thermal panels, acrylic windows, various materials	Cannula, valve, collection bags, tubes, Electronic module	Set of Components based on the analysis of parameters through TRIZ that allow measure in real time, non-invasive and that seeks animal welfare

*Berra (2009); **Canul (2017); *** Berra (2010).

Multi-screen Analysis

Time and space are established as the variables to be followed. Space is the system and its sets, the super system and subsystems. On the other hand, time is considered as the present, past and future (Martínez-Cruz, 2014). This analysis tool of TRIZ is used for the problem exploration and definition which helps in the extension of the scenario of failure for an evolution in the system (Mansoor et al., 2017).

A prototype consisting of a technique for the measurement of enteric CH_4 in cattle using a system containing a fistula surgically placed in the bovine below the transverse process of the first lumbar vertebra, a cannula and collection bags in order to store the gases and then measure them. This prototype requires performing an invasive procedure in the stomach of the cow (Berra et al., 2009).

As a present scenario, a prototype breathing chamber was analyzed for the in vivo measurement of bovine CH_4 production in Mexico, consisting of thermal panels with two acrylic windows, containing an air volume of 9.97 m^3. In this system the CH_4 mixed in the air samples is quantified with an infrared analyzer (Canul Solis et al., 2017).

Also, as part of the present scenario, we analyzed the prototype electronic module that measures the volume of gas generated in the rumen. Which is a variant of the prototype that uses the fistula in the ruminal cavity, which has a cellular communication system that uses the General Packet Radio Service (GPRS) network to send measured data via the Internet to a server. The server stores this information in a database for further analysis (Berra et al., 2010).

After multi-screen analysis, we proceeded to work with the Matrix of Technical Contradictions to choose the parameters of contradiction that allow the future design of a CH_4 meter in real time.

Matrix of Technical (System) Contradictions

The Technical Contradictions Matrix is one of the tools of TRIZ that allows to use the principles of inventiveness when a technical contradiction in the problem is identified. There are universal principles of invention, which can serve as a basis for creative innovations and technological advances. Once the problem of inventiveness or technological innovation was completely defined and what was wanted to be determined, the Matrix was used, which has as premise that the technical contradictions are those in which an element 'A' of the technological system to be improved, the same system conflicts with another 'B'.

When performing the analysis of parameters related to the prototype design, it was determined that the appropriate combination of parameters based on what the matrix of contradictions provides is:

- Parameter A: Level of automation.
- Parameter B: Stability of an object.

What is desired to improve is the level of automation so that the prototype can be used in the field, taking care of the welfare of the animal and making measurements in real time was identified as (Bukhman, 2012):

- Parameter 38 at the Automation Level: which is the capacity for that an object or technological system perform the function for which it was designed without human intervention. The lowest level of automation will be that of a manually operated object, the highest level of operation being that in which the object or a system functions independently of the human being, monitoring its own operation.

- Parameter 13. Stability of the composition of an object: is Integrity of the object or system. Composition of an object is the exact combination of elements providing the structure of the object. Stability of the composition of an object is the exact combination of elements during the given period of interest.

Considering these two parameters, the analysis was performed on the matrix which resulted in the use of inventive principles 18 and 1.

	Worsening Feature												
Inproving Features	1	2	3	12	13	14	17	18	27	28	29	38	39
1: Weight of moving object	*	-	15 8 29 34	10 14 35 40	1 35 19 39	28 27 18 40	6 29 4 38	19 1 32	1 3 11 27	28 27 35 26	28 35 26 18	26 35 18 19	35 3 24 37
2: Weight of stationary	-	*	-	13 10 29 14	26 39 1 40	28 2 10 27	28 19 32 22	19 32 35	10 28 8 3	18 26 28	10 1 35 17	2 26 35	1 28 15 35
3: Length of moving object	8 15 29 34	-	*	1 8 10 29	1 8 15 34	8 35 29 34	10 15 19	32	10 14 29 40	28 32 4	10 28 29 37	17 24 26 16	14 4 28 29
12: Shape	8 10 29 40	15 10 26 3	29 34 5 4	*	33 1 18 4	30 14 10 40	22 14 19 32	13 15 32	10 40 16	28 32 1	32 30 40	15 1 32	17 26 34 10
13: Stability of the object	21 35 2 39	26 39 1 40	13 15 1 28	22 1 18 4	*	17 9 15	35 1 32	32 3 27 16	-	13	18	1 8 35	23 35 40 3
14: Strength	1 8 40 15	40 26 27 1	1 15 8 35	10 30 35 40	13 17 35	*	30 10 40	35 19	11 3	3 27 16	3 27	15	29 35 10 14
17: Temperature	36 22 6 38	22 35 32	15 19 9	14 22 19 32	1 35 32	10 30 22 40	*	32 30 21 16	19 35 3 10	32 19 24	24	26 2 19 16	15 28 35
18: Illumination intensity	19 1 32	2 35 32	19 32 16	32 30	32 3 27	35 19	32 35 19	*	-	11 15 32	3 32	2 26 10	2 25 16
27: Reliability	3 8 10 40	3 10 8 28	15 9 14 4	35 1 16 11	-	11 28	3 35 10	11 32 13	*	32 3 11 23	11 32 1	11 13 27	1 35 29 38
28: Measurement accuracy	32 35 26 28	28 35 25 26	28 26 5 16	6 28 32	32 35 13	28 6 32	6 19 28 24	6 1 32	5 11 1 23	*	-	28 2 10 34	10 34 28 32
29: Manufacturing precision	28 32 13 18	28 35 27 9	10 28 29 37	32 30 40	30 18	3 27	19 26	3 32	11 32 1	-	*	26 28 18 23	10 18 32 39
38: Extent of automation	28 26 18 35	28 26 35 10	14 13 17 28	15 32 1 13	18 1	25 13	26 2 19	8 32 19	11 27 32	28 26 10 34	28 26 18 23	*	5 12 35 26
39: Productivity	35 26 24 37	28 27 15 3	18 4 28 38	14 10 34 40	35 3 22 39	29 28 10 18	35 21 28 10	26 17 19 1	1 35 10 38	1 10 34 28	18 10 32 1	5 12 35 26	*

Figure 1. Matrix of Technical (System) Contradictions.

- Principle 1: Segmentation. Fragmentation. Micro level transition. Divide an object or a system into separate parts. Make an object easy to disassemble. Increase the degree of fragmentation or segmentation.
- Principle 18 Mechanical vibration. Generation of a oscillating or vibratory system. Increase the frequency of vibration. Use the resonant frequency of an object. Use electrical parts instead of mechanical vibrators. Use ultrasonic and electromagnetic fields.

RESULTS AND DISCUSSION

Considering the principles set by TRIZ and laws and stages of systems evolution, it is intended to eliminate those elements that are harmful to livestock but continue to perform their function. To this end, it was proposed to use sensors to measure GHG s emissions. By obtaining these principles of inventiveness, we have the guideline to design the non-invasive and automated prototype that measures in real time the emissions of CH_4 and CO_2 from cattle. As Final Ideal Result IFR an adjustable harneswas developed (Fig. 2) which included MQ4 micro sensors for CH_4 and MQ7 for CO_2, an Arduino micro controller programmed in C ++ and an Xbee module which recorded the measurements in portable computer equipment, which allowed to obtain the measurement without the need to manipulate the animal avoiding to perform surgical procedures in this one being able to carry out the measurement in field.

Figure 2. Data Emitter.

Figure 3. Data Receiver.

According with the principle of segmentation proposed in TRIZ's contradiction matrix, the prototype design was segmented into two parts, one transmitter and one receiver wirelessly connected with radio frequency communication using a range between 865 MHz and 2.4 GHz, (Fig. 3). These modules used the network protocol called IEEE 802.15.4 to create FAST POINT-TOMULTIPOINT (point-to-multipoint) networks, or PEER-TO-PEER (peer-to-peer) networks, designed for applications requiring high data traffic, low latency and predictable communication synchronization. The prototype was placed on the specimen (Fig. 4), and the CH_4 and CO_2 emissions in ppm were recorded for 30 minutes. The data obtained were sent with the transmitter wirelessly to the receiver for display in digital form; the measurements were 25 minutes per experimental unit for 3 consecutive weeks, with a sampling frequency of 1 second; CH_4 gas values ranged from 301.99 ppm to 197.37 ppm, while CO_2 ranged from 1,701.83 ppm to 1,169.47 ppm.

In Argentina it has been tried a technique for collecting the gas produced in the rumen by a 2 cm in diameter fistula, through which the gas flows to a container nylon balloon type fixed to the back, in this case a Holstein cow of 550 kg. Once the gas has been collected for periods of 24 h, its CH_4 concentration is determined at intervals of 6 h. The daily gas production was on average 911.7 L and the concentration of CH_4 varied from 20 to 32% and represented on average 247 L d^{-1} (Bonilla-Cárdenas & Lemus-Flores, 2012).

The prototype developed by the National Institute of Agricultural Technology (INTA) only performs the measurement of CH_4 gas, this being a robust, heavy and invasive prototype, this to contain a probe that is entered inside the rumen of the cow.

The prototype of the INTA sends the data through a GPRS chip to a database, where the relationship of food type with CH_4 gas volume in L was analyzed.

For GPRS operation only the chip was registered in a telephone company and activated the data packet, this system only works with cellular signal being a problem if applied to a rural area. In contrast, the prototype of this study sends the census data of CH_4 and CO_2 gas by means of Radio Frequency (RF) system, which works in places where there is no cellular signal, another characteristic of this device is that the gas readings CH_4 and CO_2 are received in parts per million (ppm).

Figure 4. Prototype testing.

INTA developed another device called a backpack cow, where it placed a probe inside the rumen of the cow and connected it to a backpack of cylindrical form located on the upper parts of the back of the ruminant, in this way the gas was encapsulated inside the rucksack of the cow obtaining between 400 and 450 L of CH_4 gas within 24 hours (Berra, 2010).

While the quantifying prototype performed in this study detects two gases CH_4 and CO_2 being a non-invasive prototype as it performs the measurement of gases through two sensors MQ7 and MQ4 through the exhalation of the bovine however this prototype is segmented in two parts to reduce the size and weight and thus not cause discomfort to the animal.

In the prototype of the gas chamber, were obtained measurements of 173.2 L per d of CH_4, while an emission factor was 17.48 L of CH_4 per kg of dry matter consumed (Canul et al., 2017).

CONCLUSIONS

With the support of TRIZ, it was possible to find the best approximation of a measurer prototype of CH_4 and CO_2 emissions from cattle, thanks to the adequate selection of parameters and design methodologies. The IFR is a light, non-invasive prototype that does not cause harm to the animal.

For some authors specializing in the management of livestock species, the timely and responsible management of animals when making evaluations or measurements is vital. There are invasive or harmful methods that increase stress in livestock and this can be harmful at the time of consumption of the derivatives thereof.

Using TRIZ helps to expand the panorama in terms of innovation, since it allows to find the solution in a precise way to the problem raised, finding the IFR.

TRIZ is a tool that is not well exploited in Mexico, and even more so in the livestock sector. This is why, with this work, we intend to present an alternative for the design of material and equipment for livestock activities to facilitate the achievement of results.

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REFERENCES

Acosta-Flores, J.J. 2010. The field-sustance analisys (El análisis campo-sustancia). *Ingeniería, Investigación yY Tecnologí* **11**(2), 247–252 (in Spanish).

Altshuller, G. 2006. And suddenly the inventor Appeared, *TRIZ, the Theory of inventive problem solving*. (2nd ed.), Worcester. MA: published by Technical Innovation Center, Inc

Álvarez-Torres, E., Álvarez-Iglesias, J. & Fleitas-Jiménez, S. 2014. Super-contamical to estimate the GHG emited or not emited for diferents vías (Súper-contamical para calcular la cantidad de gases efecto invernadero (GEI) emitidos o dejados de emitir por diferentes vías). *Ingeniería agrícola* **4**(4), 50–55 (in Spanish).

Beltrán-Santoyo, M.A., Álvarez-Fuentes, G., Pinos-Rodríguez, J.M. & Contreras-Servín, C. 2016. Emission of methane in bovine milk production systems in the San Luis Potosí Valley, Mexico (Emisión de metano en los sistemas de producción de leche bovina en el valle de Ssan Lluis pPotosí, Mméxico). *Agrociencia* **50**, 297–305 (in Spanish).

Berra, G., Bualó, R.A., Finster, L., Zeitune, G. & Valtorta, S.E. 2010. Use of Telemetry to Measure Gas Production in the Rumen (Uso de la Telemetría para Medir la Producción de Gas en el Rumen). *FAVE Sección Ciencias Veterinarias* **9**(1), 49–55 (in Spanish).

Berra, G., Finster, L. & Valtorta, S.E. 2009. A simple technique for measuring enteric methane emissions in cows (Una técnica sencilla para la medición de emisiones de metano entérico en vacas). *FAVE Sección Ciencias Veterinarias* **8**(1), 49–56 (in Spanish).

Blackburn, T.D., Mazzuchi, T.A. & Sarkani, S. 2012. Using a TRIZ framework for systems engineering trade studies. *Systems Engineering* **15**(3), 355–367.

Bonilla-Cárdenas, J.A. & Lemus-Flores, C. 2012. Emission of enteric methane by ruminants and their contribution to global warming and climate change (Emisión de metano entérico por rumiantes y su contribución al calentamiento global y al cambio climático). *Revista Mexicana de Ciencias Pecuarias*, 215–246 (in Spanish).

Bukhman, I. 2012. TRIZ Technology for Innovation. Cubic Creativity Company

Canul Solis, J.R., Piñeiro Vázquez, A.T., Arceo Castillo, J.I., Alayón Gamboa, J.A., Ayala Burgos, A.J., Aguilar Pérez, C.F. & Ku Vera, J.C. 2017. Design and construction of low-cost respiration chambers for ruminal methane measurements in ruminants. *Revista Mexicana De Ciencias Pecuarias* **8**(2), 185–191. https://doi.org/10.22319/rmcp.v8i2.4442

Carmona, J., Bolívar, D. & Giraldo, L. 2005. Methane gas in livestock production and some alternatives to measure its emissions and reduces its impact at an environmental and productive level (El gas metano en la producción ganadera y alternativas para medir sus emisiones y aminorar su impacto a nivel ambiental y productivo). Revista Colombiana de Ciencias Pecuarias. *Colombian Journal of Animal Science and Veterinary Medicine* **18**(1), 49–63 (in Spanish).

Córdova Ames, W. 2008. TRIZ, the systematic thinking and innovation tool (TRIZ, la herramienta del pensamiento e innovación sistemática). *Contabilidad Y Negocios* **3**(6), 11 (in Spanish).

Cortes Robles, G., Machorro Rodriguez, Á., Negny, S. & LeLann, J.M. 2011. The TRIZ-CBR synergy : a knowledge based innovation process. *Int. J. Manufacturing Technology and Management* **22**(3), 233–246.

Dubeňová, M., Šima, T., Gálik, R., Mihina, Š., Vagač, G. & Boďo, S. 2014. Reduction of nitrous oxide and carbon dioxide in the pig barn piggery by different ventilation system intensities. *Agronomy Research* **12**(1), 207–214.

Latati, M., Rebouh, N.Y., Aouiche, A. & Laouar M. 2019. Modeling the functional role of the microorganisms in the daily exchanges of carbon and nitrogen in intercropping system under Mediterranean conditions. *Agronomy Research* **17**(2), 559–573. https://doi.org/10.15159/ar.19.050

Mansoor, M., Mariun, N., Toudeshki, A., Abdul Wahab, N.I., Mian, A. U. & Hojabri, M. 2017. Innovating problem solving in power quality devices: A survey based on Dynamic Voltage Restorer case (DVR). *Renewable and Sustainable Energy Reviews* **70**, 1207–1216. https://doi.org/10.1016/j.rser.2016.12.022

Martínez-Cruz, J.R. 2014. The windos of TRIZ, applications (Las ventanas de TRIZ, aplicaciones). *Ciencia UANL* **17**(66), 70–72 (in Spanish).

Moehrle, M.G. 2005. What is TRIZ? From conceptual basics to a framework for research. *Creativity and innovation management* **14**(1), 3–13.

Nakagawa, T. 2011. Education and training of creative problem solving thinking with TRIZ/USIT. *Procedia Engineering* **9**, 582–595. https://doi.org/10.1016/j.proeng.2011.03.144

Petherick, J.C. 2005. Animal welfare issues associated with extensive livestock production: The northern Australian beef cattle industry. *Applied Animal Behaviour Science* **92**(3), 211–234.

Santillán, V.S., Barra, J.D.E., Paz, F. & Cárdenas, L.O.A. 2016. Greenhouse Gas Emissions in Agricultural Systems in Mexico. *Terra Latinoamericana* **34**(1), 83–96.