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CONTENTS

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   RESULTS & DISCUSSION

   FINDINGS

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   CONCLUSIONS

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- Garg, Bhavet (2011): Towards a New Natural Gas Policy, Political Weekly, Viewed on January 01, 2012 http://epw.in/user/viewabstract.jsp

CORRELATION FOR THE PREDICTION OF EMISSION VALUES OF OXIDES OF NITROGEN AND CARBON MONOXIDE AT THE EXIT OF GAS TURBINE COMBUSTION CHAMBERS

LISSOUCK MICHEL
SR. LECTURER
ENERGY LABORATORY
UNIVERSITY OF DOUALA
CAMEROON

FOZAO KENNEDY F
SR. LECTURER
PETROLEUM RESEARCH GROUP
UNIVERSITY OF BUEA
CAMEROON

TIMBA SADRACK M.
SR. LECTURER
MECHANICS LABORATORY
UNIVERSITY OF DOUALA
CAMEROON

BAYOCK FRANÇOIS N.
ASST. LECTURER
ENERGY LABORATORY
UNIVERSITY OF DOUALA
CAMEROON

ABSTRACT
This work is based on establishing a correlation between two pollutants: the oxides of nitrogen (NOx) and carbon monoxide (CO) in exhaust gases from gas turbines. This correlation relies on a large series of measurements of the different pollutants taken at the same conditions of gas exhaust from the combustion chambers of gas turbines. From this large series of measurements, data were recorded in the EXCEL software and thereafter with the least square method following a step by step procedure, the different functions of auto correlation were generated, followed by the generation of the function of global auto correlation. This function of global auto correlation will then be smoothened, thereafter determine the function that will allow us to validate our measured data. Our generated function will be able to verify the compatibility of our results. This work started firstly with a general study of combustion; followed by some theories on the formation of pollutants in combustion chambers of gas turbines, after which we studied the theories established by researchers on the methods of prediction of the rates of pollutant emissions at the exit of combustion chambers of gas turbines, and finally we exploited the data from experiments to generate the analytico-empirical equation of emissions rate of oxides of nitrogen (NOx) with respect to those of carbon monoxide (CO) in exhaust gases of gas turbine.

KEYWORDS
oxides of nitrogen, carbon monoxide, exhaust gas, gas turbine, pollutants, auto interrelationships, emission rate.

INTRODUCTION
The struggle against the atmospheric pollution is nowadays one of stakes of the protection of the environment. Restrictions on emissions of gases to greenhouse effect since the antipollution summit of KYOTO had planned fines for the signatory countries that didn't respect their engagements concerning atmospheric pollution, and the one of COPENHAGEN that was supposed to find an agreement to take over the protocol of KYOTO which, only fixed limits for emissions of greenhouse effect gases only until 2012.

Gas turbines as a source of energy production in the industry and in the transport sector are high pollutant engines, of which the amount of entities ejected into the atmosphere should be evaluated and known.

Using mathematical tools of the analysis of pollutant formation [11], researchers have modeled the effects of operating conditions on the performance of the emissions of a gas turbine. They started with the understanding of the fact that, to calculate the production of CO, it is assumed that during combustion, fuel reacts completely first into CO and water. After, the CO reacts into CO_2 according to the rates of reactions in the faster models than the one of CO into CO_2. The rate of formation of CO remains dependent on the level of the equilibrium temperature. In the same works they estimate that to predict the emissions of non burnt hydrocarbons, rates of reaction are integrated from an initial concentration corresponding to the flux of fuel entering into the reactor [8].

Pearce [1] established an equation of nitrogen oxides at the exit of the chamber of combustion according to the characteristic parameters such as; the interior temperature of the chamber of combustion, the pressure of the admission gases, the volume of the combustion chamber, and the quality of fuel.

In the same setting of research, Tsogo and Kretschmer [10] are going to take the relation of Pearce to take two analytico - empirical relations as a basis; between the NOx and the UHC (unburnt hydrocarbons) and between UHC and CO to the exit of gas turbine combustion chamber.

The combination of the two equations obtained by Tsogo and Kretschmer drives to an indeterminate shape. No matter what ever value of CO is inserted into the formula, the value of NOx obtained will always be negative.

We must then establish an interrelation function on the basis of the results of works done by Pearce [1], and the experimental data provided by the two institutions using the least square statistical method generated with EXCEL, between the emission indices of the NOx as a function of the emission indices of CO in exhaust gases of gas turbine. Then this function will be inserted in software to validate results of the interrelationship while using the experimental data provided by the two research laboratories (University of Laval and Aeronautical Research).

In this part we analyze the experimental data of these researchers to establish an interrelation that will permit us to evaluate emission indices of oxides of nitrogen (NOx) as a function of those of carbon monoxide (CO) at the exit of gas turbine combustion chamber.

MATERIALS AND METHODS

The data were collected in gas turbine by the laboratory of combustion of the University of Lawal (Canada) for chambers ARL 36, 38, 42 and the Aeronautical Research Laboratory (Australia) for J79-17A, J79-17C, F101 and PW.

- The experimental data of Figs.1, 2, 7 come from the reference [1]
- The experimental data of Figs.3, 4 & 5 come from the reference [2] & [3]
- The experimental data of Fig. 6 come from the reference [4]

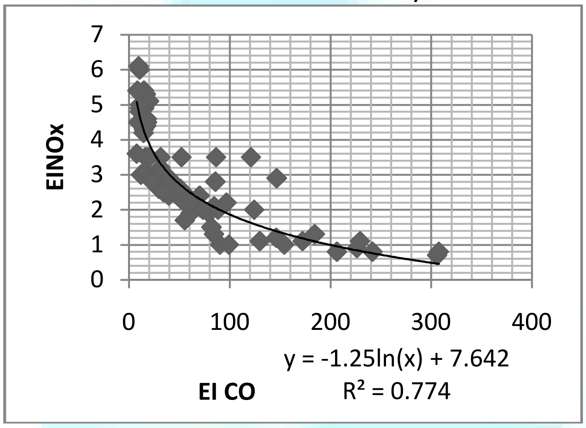
DEVELOPMENT OF THE NOX/CO RELATION

In [1], authors propose the following interrelationship for the prediction of emission indices (EI) of NOx at the exit of gas turbine combustion chamber:

$$EI_{NO_x} = 27.03 e^{\left(\frac{-21670}{T_{Stéoch}}\right)} P_3^{0.66} \times \left(1 - e^{\left[-0.7325\left\{\frac{V_{pz} P_3^{0.6}}{m_a T_m^{0.5}}\right\}^{0.404}\right]}\right) \quad (1)$$

The standard deviation of results signaled here is 33,3% in relation to the experimental data (a total of 2200 points of measurements), which is very respectable considering the inherent mistakes to techniques of emissions measurements themselves, and especially of the important number of analyzed combustion chambers (a total of 9 distinct chamber types). This interrelationship presents the certain advantage of making use of operational parameters (pressure and temperature) and of really accessible dimension (volume of the primary zone) of a gas turbine combustion chamber.
Based on the available experimental data for emissions of nitrogen compounds (NOx) and of carbon monoxide (CO) gathered during the same combustion tests evoked here below, it is observed in certain chambers, a narrower relation between emissions of NOx and those of CO.

FIGURE 1: RELATION BETWEEN EINOx AND EICO 1/3 ARLS 38 CHAMBER.



1/3 ARLS designate the scale 1/3 of the combustion chamber of type (Aeronautical Research Laboratory of Melbourne in Australia), while the number 38 designates a fuel number. Fig.1 is obtained from 74 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide can be observed. We note the R2 value of 0.774.

FIGURE2: RELATION BETWEEN EINOx AND EICO, 1/3 ARLS 42 CHAMBER

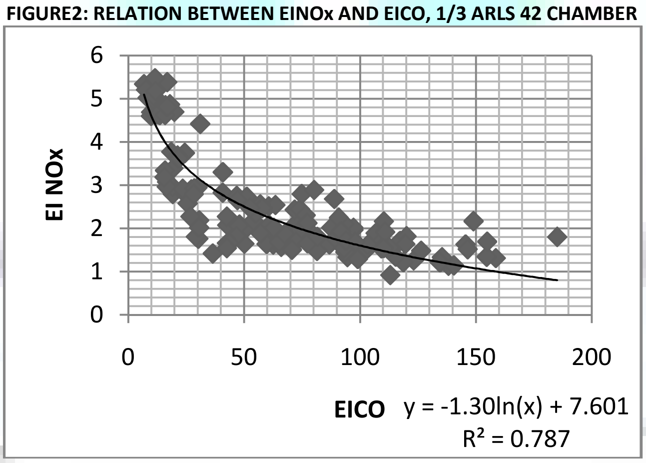


Fig. 2 is obtained from 148 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide is appreciated as being relatively strong, as testified by the high value of R2 of 0.787.

FIGURE 3: RELATION BETWEEN EINOx AND EICO, F 101 CHAMBER

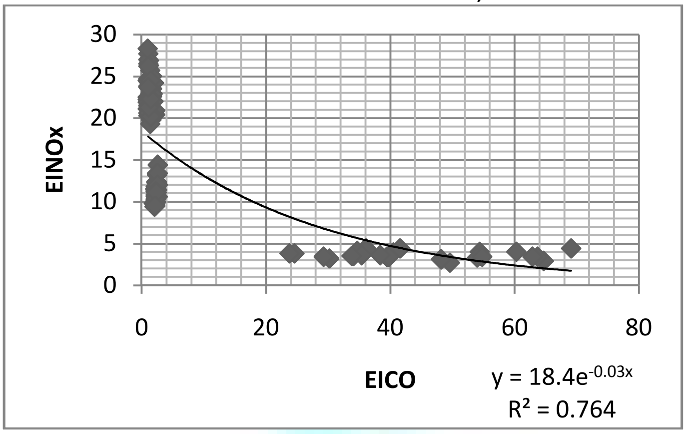


Fig.3 is obtained from 105 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide is appreciated as being relatively strong, as testified by the high value of R2 of 0.76.

FIGURE 4: RELATION BETWEEN EINOx AND EICO, J79 17-A CHAMBER

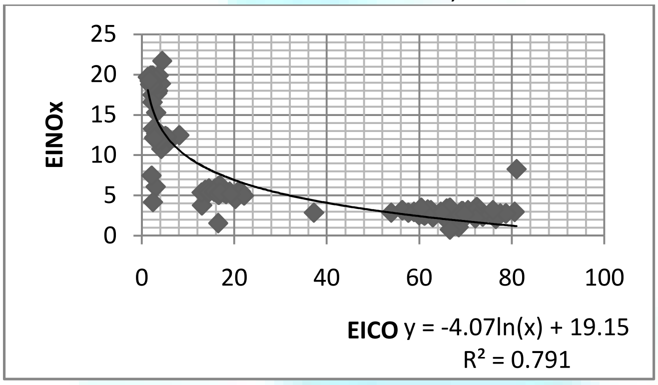


Fig.4 is obtained from 126 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide is appreciated as being relatively strong, as testified by the high value of R2 of 0.79.

FIGURE 5: RELATION BETWEEN EINOx AND EICO, J79 17-C CHAMBER.

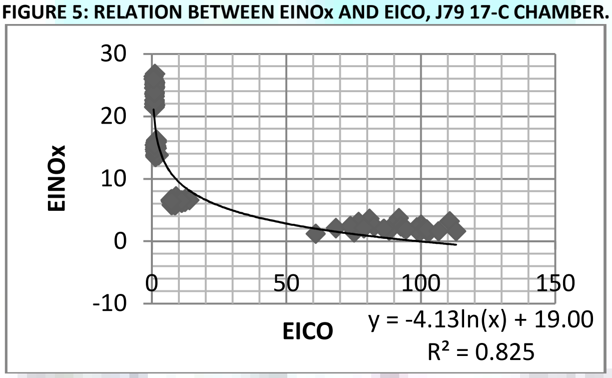


Fig.5 is obtained from 126 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide is appreciated as being relatively strong, as testified by the high value of R2 of 0.825.

FIGURE 6: RELATION BETWEEN EINOx AND EICO, PW CHAMBER.

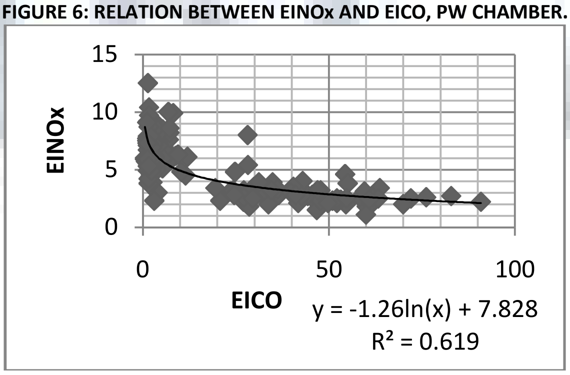


Fig.6 is obtained from 195 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide is appreciated as being relatively strong, as testified by the high value of R2 of 0.619.

FIGURE 7: RELATION BETWEEN EINOx AND EICO, ARL 36 CHAMBER

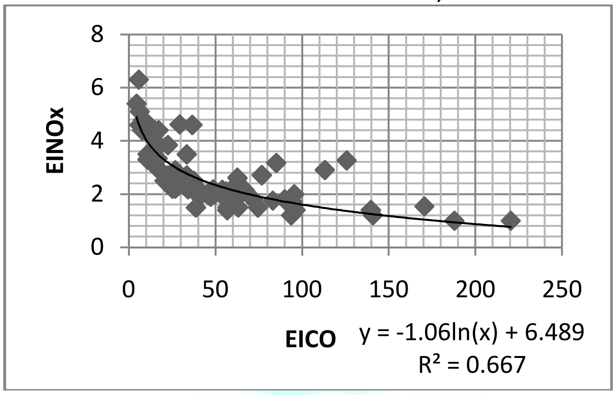
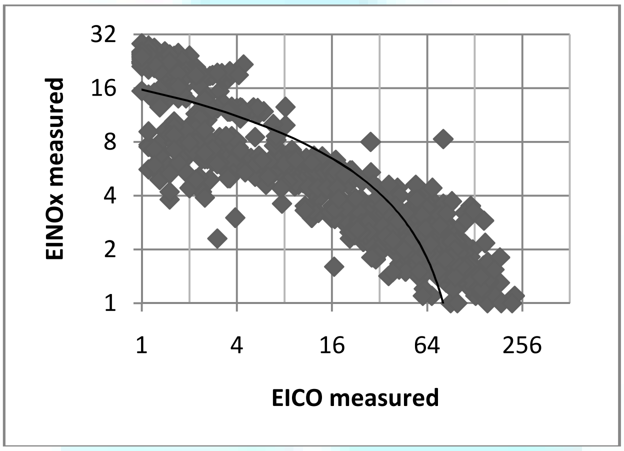


Fig.7 is obtained from 86 experimental points. The existence of a relation between the emission indices of oxides of nitrogen and the emission indices of carbon monoxide is not strong, as testified by the value of R2 of 0.66. Nevertheless, a good correlation tendency is observed.

DEVELOPMENT OF THE CORRELATION

Fig.8 below is representative of 1534 experimental data points of measurements obtained from 7 gas turbine combustion chambers. The existence of a relation between the emission indices of oxides of nitrogen (NOx) and the emission indices of carbon monoxide(CO) is appreciated as being relatively strong, as testified by the value high of R2 of 0,71735201.

FIGURE 8: ANALYSIS OF THE 7 COMBUSTION CHAMBERS



We will have the auto correlation function as follows:

$$NOx = -3.37\ln(CO) + 15.81 \quad (2)$$

From observations of the previous figures, the two indices would be combined through a logarithmic relation as:

$$EINOx = A\ln(EICO) + B \quad (3)$$

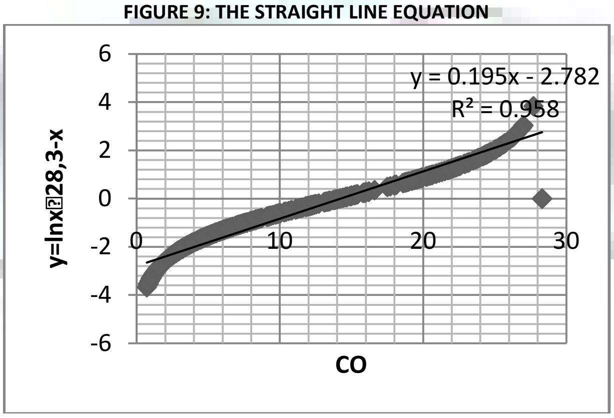
Our auto-correlation index is not as strong as we hoped. We must therefore proceed by a non linear adjustment empiric method.

Let us assume an exponential progression, and as the limit of 28.3 is a tentative data, we try different changes of variables, with the following function giving some good results.

$$y_1 = \ln\left(\frac{X}{28.3 - X}\right) \quad (4)$$

y_1 is the function that will represent possible best forms of cloud, x represents those of NOx, and 28.3 the maximum value of NOx.

FIGURE 9: THE STRAIGHT LINE EQUATION



We determined y_2 (straight line equation), using the graphic method:

We obtain the following result:

$$y_2 = 0{,}19t - 2.78 \quad (5)$$

with R2=0.958.

Therefore considering equations (4) and (5), X verifies the equality given by:

$$\ln\left(\frac{X}{28.3 - X}\right) = 0.196t - 2.788 \quad (6)$$

Which gives

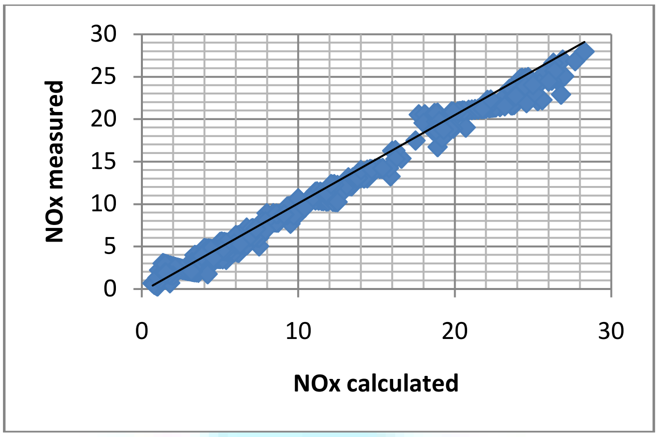
$$X = \frac{28.3}{1+e^{(-0.19t+2.788)}} \quad (7)$$

The value of R2 obtained here is 0.84. We will therefore have the general form of the equation given by:

$$NOx = \frac{28.3}{1+e^{(-0.19CO+2.788)}} \quad (8)$$

The experimental data and calculated values using eq. 8 were plotted as shown on Fig.10.

FIGURE10: RELATION BETWEEN MEASURED EINOX AND CALCULATED EINOx:



(ARL38, PW, J79-17A, J79-17C, F101, ARL 42, and ARL36)

DISCUSSION

In a general manner, the results observed on Fig.10 can be considered as satisfactory:

To its merit, the correlation relies an important quantity of experimental data (1553 data points), at the same time as it covers an important number of combustion chambers (a total of 7, with different scales of certainty).

Concerning the precision of the correlation, one can estimate that it is respectable, considering the number of chambers concerned: The standard deviation of results in relation to the experimental values for the set of analyzed data is 28%, and it is distinctly better for these chambers when they are considered individually (ARL, J79-17A and C, PW, 1/3ARL). Hence because the precision given by the equation (1) is 33% [1], and that the precision of equation (8) appreciates itself naturally in relationship with that of equation (1), it becomes obvious that the results gotten in this survey are effectively respectable. One can observe however from the Fig.2 that the result is more precise in the elevated emission zone, whereas it is less in the low emission zone. The level of emissions varies from one combustion chamber to another, and Fig.2 to Fig.8 indicate that the relation between emissions of the oxides of nitrogen (NOx) and carbon monoxide, although being the same in nature, remain well peculiar from one combustion chamber to another. This is the reason in the variation at the level of constants, as well as in the exponents in the different relationships of the different combustion chambers. This state of affairs can be explained by the quantity of data analyzed in each of the cases, by the nature of the chambers (mode of construction), and even by the mode of functioning of the chambers (mode of air injection, the nature of premixed or no combustible mixture etc.).

TABLE 1: COMPARISON OF THE 2 CORRELATIONS

correlation	R^2	Standard deviation with respect of the experimental data
$EI_{NOx} = 27.03e^{\left(\frac{-21670}{T_{Stéoch}}\right)}P_3^{0.66} \times \left(1 - e^{\left[-0.7325\left\{\frac{V_{pz}P_3^{0.6}}{m_a T_m^{0.5}}\right\}^{0.404}\right]}\right)$	0.67	33%
$NOx = \frac{28.3}{1+e^{(-0.19CO+2.788)}}$	0.85	15%

The tentative generalization of the different constants and exponents tried on Fig.10 which is the starting point of subsequent empirical adjustments, can be reconsidered as having been fruitful. It confirms immediately that beyond the chambers construction models, there exists (as regards to the chemistry of combustion) altogether relations between the different emissions recorded during the same operation of combustion in combustion chambers of gas turbines. It however remains obvious that the correlation (8) is far from being a panacea and that it is only applicable in the domain where it seems to give some respectable results. The objective here is to enable the practitioner to avoid taking heavy experimental measures, as well as from time to time in terms of available means (equipment) invest from taking measurements. It is a question in the approach of exploiting the existence of formal relations between emissions of different nature resulting from the same combustion operation, a measure of emissions of oxides of nitrogen can permit the deduction through calculations, the corresponding value of emissions of carbon monoxide and vice versa. This would permit an easy analysis of the existing models as well a comfortable projection on future models.

The correlation proposed in this study, although surely requiring some particular adjustments for combustion chambers not considered in here, can be proposed for the combustion chambers << ARLS, J79-17A and C, PW, 1/3ARL and F 101 >>

The development of correlation (8) from several hundreds of experimental data obtained from several types of combustion chambers and several fuels, gives the impression that it is effectively applicable (with some adjustments in particular cases) for several currently functional combustion chambers and for future development of other combustion chambers. This could effectively avoid the necessity of collecting experimental data in some cases. Otherwise, the possibility through this correlation to determine the content of CO in exhaust gases at the exit of the combustion chambers of gas turbines when the content of NOx is known and vise versa, shows that it necessitates the existence of formal relations between the different pollutants constituting the exhaust gases in different combustion operations, and that these correlations between different pollutants could be exploited for final deductions through calculations, thus experimental measures (not always comfortable) will become secondary.

CONCLUSION

The planet knows a period of global climatic change without precedent to the multiple environmental impacts which human activity is in part responsible. The reduction of atmospheric pollution is a matter of fundamental importance nowadays considering the evolution of the industrial and technological development, and more and more of environmental requirements in relation to air pollution due to gas turbine combustion, piston engines, products transformation industries and others. Emissions of oxides of nitrogen (NOx), of carbon monoxide (CO), of non burnt hydrocarbons (HC) are subjected to limits fixed by the legislator in many countries, because of their poisonous nature beyond certain concentrations in air. However, the analytic methods of determination of quantities of emissions are not perfectly clarified, because of lack of complete understanding of phenomena governing the formation of pollutants.

A few methods of reduction of pollutants (NOx, CO, HC) proposed by some researchers have been presented in this work, and in the same other, a few methods of the prediction of these gas pollutants. And in addition a correlation permitting the prediction of the rate of emission of oxides of nitrogen at the exit of gas turbine combustion chambers, once the rate of emission of carbon monoxide is known and vice versa was developed.

At this level, it is necessary to continue to do more literature review in order to have more data and theories existing on the prediction of pollutant emissions and their formations.

Concerning the established correlation, we are going to pursue studies firstly to to determine the level emission of CO at the exhaust of the DOUALA IUT furnace, to introduce our empirical equation and observe the different results obtained. Thereafter, for the establishment of a correlation, we need to take account of the operating parameters influencing the formation of gases and also those intervening in the conception of the gas turbine combustion chambers. And also to determine a correlation between the three pollutants (NOx, CO, HC) at the exit of gas turbine combustion chambers. It is therefore necessary to find other sources of information and research works on this domain.

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