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Optimization of 2-α-Chloroethylphosphonic acid synthesis-important intermediate product in the production of phosphonates through homolytic phosphorylation method of vinyl acetate by dimethyl phosphite

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Abstract: The discovery in 1954 by Pudovik A.N., of the phosphorylation reaction [1] has made the method one of the most important, easiest and accessible ways for synthesis of very large spectra of phosphonates. The interest for this synthesis resides in the multiple medico-biological activities, the properties and the uses of the products resulting from the aforesaid synthesis. As a matter of fact, phosphonates are used in medicine for HIV therapy (tenofovir), osteoporosis treatment during women menopause, in agriculture as plant growth regulator, herbicides and fungicides; they also served as lubricants and fuel additives, anticorrosion additives, extractants and detergents. Phosphonates are equally used for eutrophication of aquatic environments to improve the fish breeding (fish farming) outcome. For all these different reasons, the challenge for 2-α-chloroethylphosphonic

acid synthesis optimisation-an important intermediate product in phosphonates production was undertaken.In a four neck-reactor of 0.25L capacity equipped with an agitator, a thermometer, a reverse refrigerator, a funnel with tap and paddle for inert gas introduction, 80mL of freshly distilled dimethyl phosphite has been poured at a temperature between 155-160°C. With intensive agitation in nitrogen atmosphere, 0.4mL of di-tertio-butyl peroxide has been added. At the end of the dosage, the mixed product is agitated for thirty (30) more minutes at the same temperature gap (155-160°C); the non-reacted dimethyl phosphite excess is extracted through a water boiling bain-marie at a residual pressure of 20mm Hg. The remaining part is farther distilled under vacuum conditions, collecting the fraction of boiling temperature 108-110°C (at a pressure of 4mmHg). The 2-dimethoxy-phosphoryl acetic acid ethyl ester is once more purified with 1g of sodium bicarbonate in order to extract the traces of dimethyl phosphite. The final resulting yield is: 36.0g-(86.7%) n_D^{20}=1.4365

Keywords: phosphorylation, reactor, inert gas, 2-dimethoxy-phosphoryl acetic acid ethyl ester, plant growth regulator, corrosion additives, fuel additives.

Résumé : La découverte en 1954 par Pudovik A.N., de la réaction de phosphorylation [1] a fait de cette méthode une des plus importantes, simples et accessibles voies de synthèse de larges spectres de phosphonates. L'intérêt de cette synthèse réside dans les multiples activités médico-biologiques, les propriétés et les utilités des produits issus de ladite synthèse.

En effet, les phosphonates sont utilisés en médecine pour la thérapie du VIH-SIDA (tenofovir); le traitement de l'ostéoporose lors de la ménopause chez les femmes; en agriculture, ce sont des régulateurs de croissance des plantes, des herbicides et des fongicides; ils sont de même utilisés comme lubrifiants et additifs dans les carburants, additifs anti-corrosion, extractants et detergents etc. Les phosphonates sont également utilisés pour l'eutrophisation des milieux aquatiques dans le cadre de l'amélioration des rendements en pisciculture. Pour toutes ces différentes raisons, l'optimisation de l'acide 2-α-chloroethyle phosphonique –un important produit intermédiaire dans la production de phosphonates a été entreprise.

Dans un réacteur à quatre cols de 0,25 litre de capacité muni d'un agitateur, d'un thermomètre, d'un réfrigérateur inverse, d'un entonnoir à robinet et d'un barboteur pour l'introduction de gaz inerte, on verse 80 ml de phosphite de diméthyle fraîchement distillé et à la température de 155-160°C avec une intense agitation dans l'atmosphère d'azote on ajoute 0,4 ml de di-tertio-butyle peroxyde, à la fin du dosage, le mélange est agité encore pendant 30 minutes à la même température (155-160°C), l'excédent de phosphite de diméthyle n'ayant pas réagi est extrait à l'aide du bain-marie d'eau bouillante à pression résiduelle de 20mm de Hg. Le reste est ensuite distillé sous vide en recueillant la fraction à téb.(température d'ébullition) 108-110°C (4mm Hg). Le 2-diméthoxy-phosphoryle ester éthylique d'acide acétique est à nouveau distillé (purifié) avec 1g de bicarbonate de sodium pour en extraire les traces de phosphite de diméthyle. Le rendement obtenu est de : 36,0g-(86,7%) n_D^{20}=1,4365.

Mots clés: phosphorylation, réacteur, gaz inerte, 2-diméthoxy-phosphoryle ester éthylique d'acide acétique, régulateur de croissance des plantes, additifs anti-corrosion additives de carburants.

INTRODUCTION

The synthesis of numerous organo-phosphoric compounds through homolytic phosphorylation [2-4] of unsaturated compounds by dialkyl phosphites, phosphines, elemental phosphorus etc. [3, 5-7] has made a significant progress during the past years. The addition reaction includes homolytic steps, which induce the initiation that unfold the presence of certain substances [2-4] capable generating, radicals in specific conditions. The particular characteristics of the reaction are the indication of relatively low selectivity and a large spectrum of isomeric products yield [6].

In case of initiation with light or ionizing emissions, it is important to analyse meticulously the possibility of homolytic bond rupture because, *a priori*, that fact alone should not be considered as the demonstration of homolytic process [3, 4].

Based on the present works on kinetics and mechanism of the homolytic phosphorylation process, the challenge is to optimize the process of 2-α-chloroethylphosphonic acid production. Series of experiments were made in order to appreciate the influence of temperature, the relation between reagents, the choice and the concentration of the initiator [7-9] on the course of the reaction. Those experiments allowed getting the ideal temperature range for optimal synthesis conditions ranging between-145-160°C.

MATERIALS AND METHODS.

The quantitative estimation of a reactor for the production of 10^6kg per annum of phosphonate was made. The reaction could be realized either, in a reactor of ideal mixture or in a cascade of ideal mixing reactors depending on the bias level to be reached.

The choice of reactor for any reaction is intimately associated with the kinetics, the hydrodynamic regime (hydrodynamics) and thermo-physic parameters of the later.

The homolytic phosphorylation process of non-saturated compounds can be written:

A + B → C, where:

A = non-saturated compound,

B = dimethyl phosphite and,

C = Product of reaction (phosphonates).

The kinetic equation at optimal temperature of this reaction writes: [2, 4-6]

$r = dC_A/dt = kC^m = kC^{0.89}$ (1)

r = Velocity of the reaction or velocity rate, in mole/dm^3.sec ;

k = Velocity constant or rate constant, in s^{-1};

C_A = concentration of the non-saturated compound, in kmole/m^3;

M = Reaction order (rank) [m=0.89].

It is important to remind that, the reactant B is brought in excess, five times greater the molar value of the reactant A.

Once the kinetic equation is established (known), it becomes easy to determine the time of stay (time of residence) and the volume of ideal mixing reactor necessary to conduct the reaction (see table 1).

Thus, $t_{mix.} = (C_{AO}-C_{AF})/kC^{0.89}$ (2)

t_{mix} = time of stay of a reactor of ideal mixture;

C_{AO} = initial concentration of reactant A;

C_{AF} = final concentration of reactant A.

With a conversion of reactant A equals to X=0.95 by assumption, the final concentration is:

$C_{AF} = C_{AO}(1-0.95) = 1.8(1-0.95) = 0.09 kmole/m^3$

$K = 40.07.10^{-3}s^{-1}$ and the time of stay:

$t_{mix} .= (1.8-0.09)/40.0710^{-3}*0.09^{0.89} = 363.8$ seconds

The volume of the reactor is determined through the expression:

$V_{mix} .= q* t_{mix}$. (3) where,

V_{mix} = volume of the reactor of ideal mixture;

Q = production in m^3/s.

Thus, $V_{mix} = 0.1*363.8 = 36.4m^3$

The corresponding volume of a piston flow reactor can be known if the time of stay $t_{pist.}$ is determined.

So, $t_{pist.} = [C_{AO}-C_{AF}]^{1-m}/(1-m)k$ (4)- (integral reactor)

$t_{pist.} = (1.8^{0.11}-0.09^{0.11})/40.07*10^{-3}*0.11 = 54.4$ seconds;

the resulting volume is then:

$V_{pist} .= 0.1*54.4 = 5.44m^3 \cong 5m^3$

Wherefore, $V_{mix}=7\ V_{pist}$. It appears clearly that using a piston flow reactor will result in a seven (07) times economy of materials. Inside a piston flow reactor, the time of stay is the same for all particles (molecules) of reaction mass.

However, the difficulty to harmonize (standardize) the temperature (profile) along the reactor and its diameter is known as the major insufficiency of this kind of reactors. In order to sidestep (skirt) this type of difficulties, cascade of ideal mixing reactors can be used.

The synthesis technology is based on the following physico-chemical processes:

1- Interaction of dimethyl phosphite with the vinyl acetate in the presence of the di-tertiary-butyl peroxide;

2- Distillation under vacuum with extraction of phosphonate;

3- Action of anhydrous hydrogen chloride on the phosphonate.

The technological scheme is shown on **Figure.1**

In reactor (1) [cascade of 4 reactors] equipped with an agitator (to ensure homogenous and deep mixture) were charged dimethyl phosphite and vinyl acetate, the dosimeter (2) enables introducing initiator (di-tertiary butyl peroxide).

A temperature setpoint of 160°C is kept with water vapour at160°C. At the end of the synthesis, the product is driven to the rectification column (3) where the non-reacted dimethyl phosphite is extracted.

In fact, the vapours of dimethyl phosphite condensed in the refrigerator (6) are sent to the stage of synthesis beginning. The obtained product in the cuve of column (3) is sent for distillation under vacuum in column (4). From upper part of column (4), the purified phosphonate is cooled with

refrigerator 6 and stocked in the vessel (8). From its lower part, the telomeres are forwarded to the vessel (7) provided for residues. The phosphonate obtained is convoyed from vessel 8 to reactor (9) where the anhydrous hydrogen chloride is injected. The temperature setpoint of the reactor at that stage is kept constant using water steam (vapours) at 145-160°C. At the end of the process, the reaction mass is sent for farther purification.

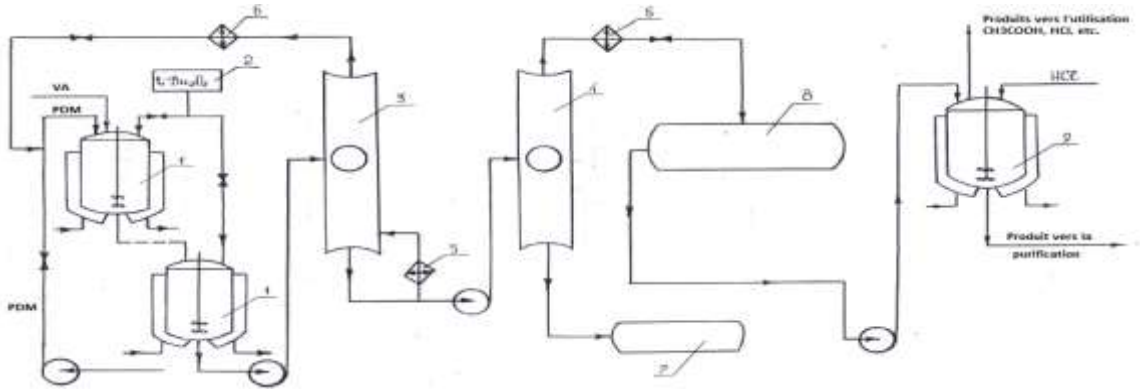

Figure 1: Scheme of 2-α-chloro-ethylphosphonic acid production

RESULTS AND DISCUSSION.

The appropriate determination of a reaction kinetic equation is the basement for the adequate choice of its reactor. As a matter of fact, this unfolds high desired product yield, resources, materials and energy saving outcomes. The use of a piton flow reactor leads most of the time to local overheating (for exothermic reactions) or local cooling (for endothermic reactions). All these phenomena can cause a thermal destruction of reaction mass and conduct to reactor local embrittlement.

Table 1: Accrued volume value of reactors during homolytic phosphorylation of non-saturated compounds.

Reactor numbers in the cascade, n	Accrued volume of reactors, m^3
1	3
2	6
3	9
4	12
5	15
6	18
7	21
8	24
9	27
10	30
11	33
12	36

According to **Figure 2**, the volume of an ideal mixing reactor in the cascade is equivalent to $3m^3$ and the time of stay t_{mix}.=V/q=3/0.1=30seconds.

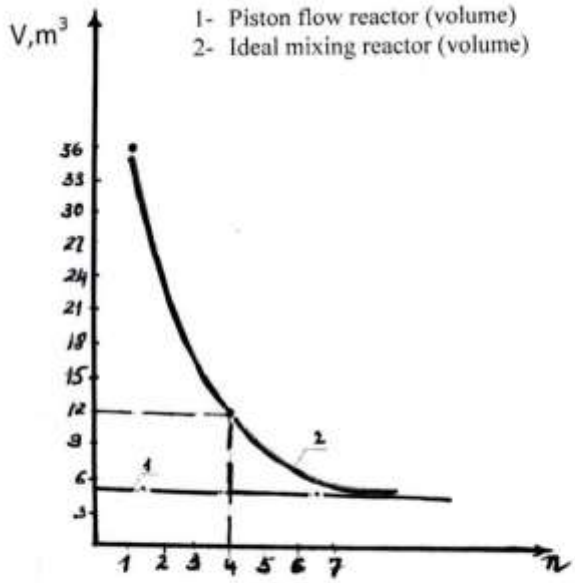

Figure 2: Reactors accrued volume in the cascade according to their number during homolytic phosphorylation of unsaturated compounds (Flow structure).

The concentration at the exit of each reactor is determined by the formula:

$t_{mix}*kC^m=C_{AO}-C_{Ai}$ (5), which means,

$y=1.202*C^{0.89}+C_{Ai}-1.8$ (6)

Solving graphically the equation (5) through C_{Ai}, we get the values recorded in **Table.2** below.

Table 2: Concentration values variation during the homolitic phosphorylation process of non-saturated compounds.

Concentration C_{Ai}	**Values in kmole/m^3**
C_{AO}	1.8
C_{A1}	0.8
C_{A2}	0.34
C_{A3}	0.14
C_{A4}	0.06

From the obtained results and the observation of the graphics **Figure 2 and 3**, it appears that the accrued time of stay in the cascade of reactors is 120 seconds, which is smaller than t_{mix} (236 seconds) but greater than $t_{pist.}$ (54 seconds).

Then from **Figure 3**, it comes out that, with the increase of reactor number in the cascade, the time of stay and the accrued volume are decreasing. The use of cascade of reactors is linked to the fact that, the micro-level bias is easily achieved in these conditions.

In the cascade, there are four (4) ideal mixing reactors because that quantity allowed largely achieving the satisfactory mixing level. Apart from that great advantage, the use of cascade also assures economy of time, high conversion rate of the reagents and less resource in energy, in heat, in materials and others. The cascade of ideal mixing reactors also permits to correct the weaknesses (inadequacy) of the ideal reactor for which, 67% of the particles are inside the volume with a time of stay less than average and reduce for three times the volume of the reactor ($12m^3$ instead of $36m^3$!).

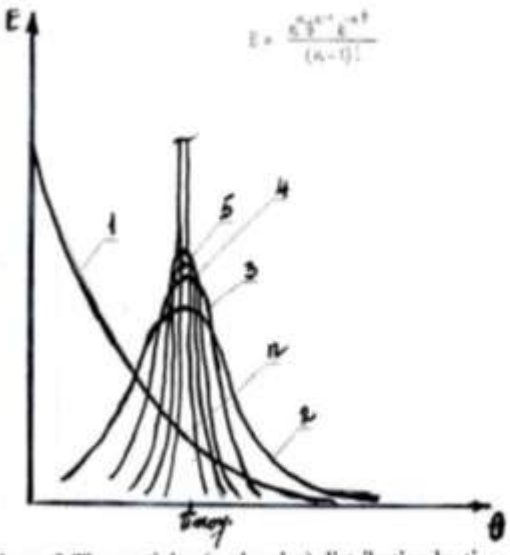

Figure:3 The particles (molecules) distribution by time of stay in function of reactors number in the cascade during homolytic phosphorylation of vinyl acetate.

The conducted experiments have led to a much elaborated technology to obtain "ethrel"-intermediate product in phosphonates synthesis.

CONCLUSION

The kinetic equation of the homolytic phosphorylation of unsaturated compounds was established and possible mechanisms proposed.

On the basis of kinetic equation, the mechanisms and series of experiments, it was demonstrated that the limiting stage for the homolytic phosphorylation process of the unsaturated carboxylic acid esters is the stage of chain development with cyclic intermediate structures more or less stable capable of hydrogen atom avulsion from dimethyl phosphite.

The conditions of homolytic phosphorylation reaction of unsaturated carboxylic acid esters by dimethyl phosphite were optimized and the consistent method of synthesis developed.

The use of cascade of ideal mixing reactor during homolytic phosphorylation synthesis was fund to be an important issue to sidestep the major insufficiencies observed while using the ideal mixing or piston flow reactors.

The appropriate technological scheme (diagram) of phosphonates synthesis was proposed and the chemical ideal mixing reactor to obtain 2-dimethoxyphosphoryl ethanol-"ethrel"- important intermediate product for the synthesis of plant growth regulator was developed.

REFERENCES.

1. A.N. Pudovik and I.V. Konovalova , Zh. Obshch. Khim., 1959, 29, 5,.3342.
2. I.A, Novakov, A.I, Rakhimov, Features of homolytic organophosphorus synthesis and its application. *Russian Journal of General Chemistry*, 2016, 86, 3, 364-367.
3. S.I. Verkhoturova, S.N. Arbuzova, T.I. Kazantseva, N.K. Gusarova, B.A. Trofimov, Phosphorylation of alkyl methane sulfonates with elemental phosphorus in a strongly basic medium: synthesis of alkylphosphonic acids. //Russian Journal of General Chemistry, 2016, 87, 88, 1876-1878.
4. Ya. A. Levin and E.I.Varkunova, Gomoliticheskaya khimiya fosfora (Homolytic phosphorous chemistry), Moscow: Nauka, 1978.
5. Adébo Félix ELEGBEDE. "Cinétique et mécanismes des réactions de phosphorylation homolytique des composés non saturés." Thèse de Doctorat, Volgograd, Russie 1993, 131p.
6. A.S.Davies, R. W. Dennis, A kinetic study of and scission of phosphoryl radicals // J. Organometal Chem.-1972, 10, P.33-35.
7. Sassin R., Olsewski W. F., Russel S. R. Phosphorus derivatives of fatty acids V. 111. Addition of dialkyl phosphonates to unsaturated Compounds //J. Am. Soc.-V.81-P.6275-6277.
8. I.S.Nazimov, Ya.E. Popovitch, I.D. Nazimov, G.G. Sergeenko, E.S. Batyeva, V.A. Al'fonsov, Cherkasov Thiophosphorylation of higher olefins with O, O-dimethyl phosphorothionate. R.A. //Russian Journal of General Chemistry, 2007, 77, 11, 1976-1977.
9. De la réactivité (de l'affinité réactionnelle) de allyle et vinyle acétate au cours de la reaction de phosphorylation. RAkhimov A.I., Elégbédé F.A., //NIITECHIM CHERCASS 1992, 203 XP92, 9 .

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