

# PRESENT-DAY CONDITION OF FLUOROAROMATIC COMPOUNDS PRODUCTION TECHNOLOGY

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Here we describe effectiveness of interphase transfer catalysts use to obtain polyfluoroaromatic compounds by potassium fluoride influence on polychlorobenzenes. Such catalysts hexaethylguanidine chloride, tetra-(diethylamino)- phosphonium bromide are involved stabilization of intermediate  $\sigma$ -complex. Catalytic participation of polyethers (tetraethyleneglycol dimethyl ether, 18-crown-6) in fluorodechlorinating process doesn't go beyond increasing "active" fluoride-ion concentration. Here we consider the opportunities of mechanic and chemical technology application to synthesize fluoroaromatic compounds by substituting chlorine for fluorine in the solid phase of chloroaromatic compounds and fluorides of alkali, alkali-landed metals composite mixtures based on them. We also discuss the question regarding synthesis of fluoroaromatic compounds out of commercial chlorofluorocarbons (freons) and polyfluoroolefines.

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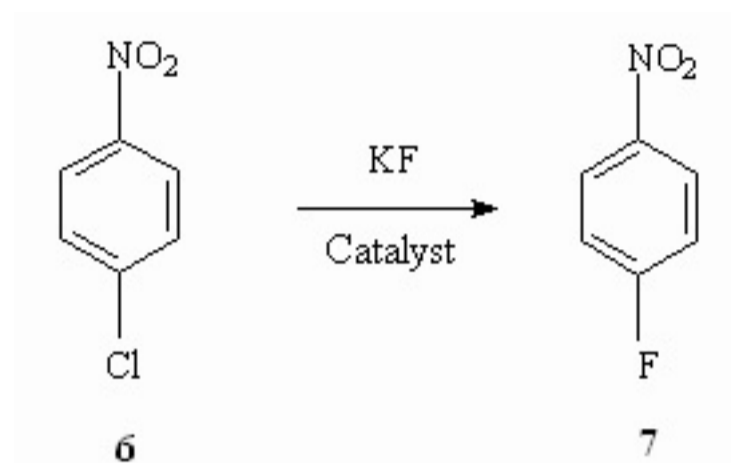
References

**1. Hexafluorobenzene synthesis by potassium fluoride influencing hexachlorobenzene in the presence of catalysts (Continuation).**

The presence of two nitro-groups in benzene ring forwards chlorine exchange for fluorine under the influence of KF, though the process passes at high temperature, while the use of  $\text{Ph}_4\text{P}^+\text{Cl}^-$  salt as a catalysts allows low the temperature of process [44].

Such salts based on aminophosphazene as 1,1,1,3,3,3-hexapyrrolidino-diphosphazene chloride chloride 1,1,1,3,3,3-hexapiperidino- diphosphazene chloride are effective catalysts for chlorine exchange for fluorine under the influence of alkali metals' fluorides or ammonium fluoride. Thus, the reaction of 2,5-dichloro-2-trifluoropyridine and KF in the sulpholane -chlorobenzene solvents' system at 215 °C produces 3-chloro-2,4-tetrafluoropyridine with the yield of 75% and pentafluoropyridine with the yield of 24% in the presence of these salts [44]. 2,6-Difluorobenzaldehyde was obtained out of 2-chloro-6-fluorobenzaldehyde by KF influence in chlorobenzene at 190 °C , it's yield was about 88.7 - 88.5 % [44].

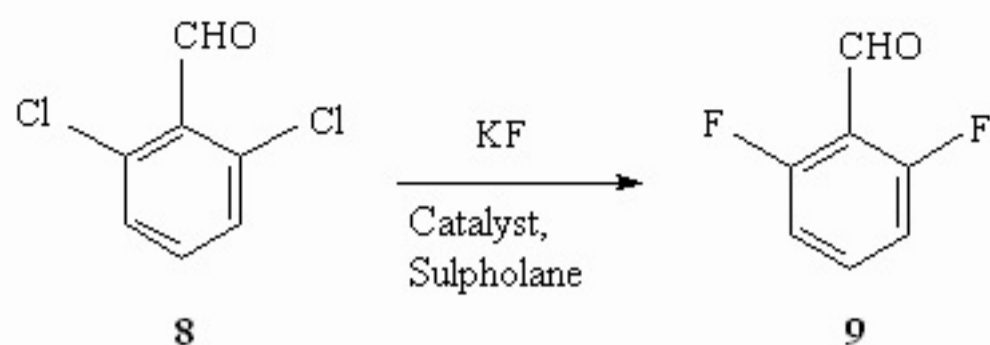
The carrying out of chlorine for fluorine exchange process in para-chloronitrobenzene proved to be effective when carrying the process out in bipolar aprotic solvents in the presence of Ph<sub>4</sub>PBr and **4** (Table 7).



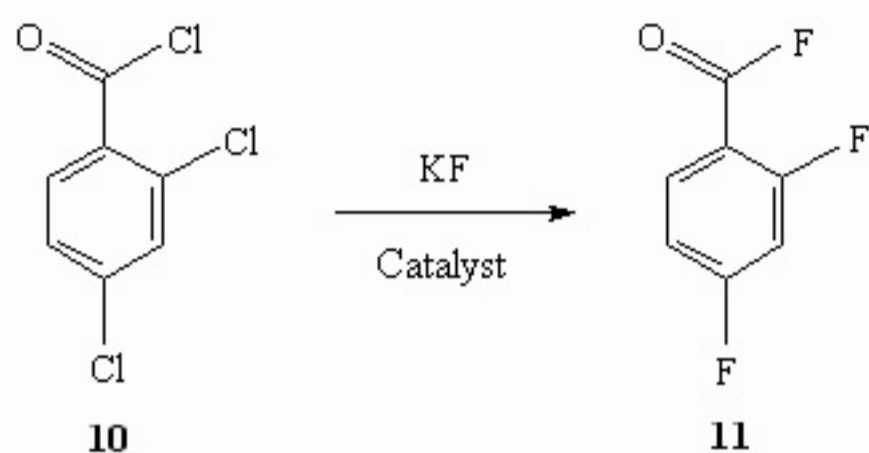
**Table 7.** Fluorinating the Benzene Chlorine Derivatives by Potassium Fluoride in the Presence of Catalyst

Substrate	Solvent (vol. %)	Catalyst (% mol.)	T, °C	Time, h	Yield (conversion) %	Ref.
<b>6</b>		Ph <sub>4</sub> PBr (1.3)	190	10	(30)	<b>57</b>
		(Et <sub>2</sub> N) <sub>4</sub> PBr (1)	180	20	88	
		(Et <sub>2</sub> N) <sub>4</sub> PBr (1.3)	190	10	(30)	
	Sulpholane (70)	Ph <sub>4</sub> PBr (1.6)	180	5	(40)	
	Sulpholane (130)	Ph <sub>4</sub> PBr (1.6)	180	6	60 (71)	
	Sulpholane (250)	Ph <sub>4</sub> PBr (1.6)	180	4	80 (94)	
	Me <sub>2</sub> SO (130)	CNC (1.0)	170	5	96	
	Me <sub>2</sub> SO (130)	(Et <sub>2</sub> N) <sub>4</sub> PBr (1.0)	170	6	93	
	Me <sub>2</sub> SO (130)	Ph <sub>4</sub> PBr (1.0)	170	6	89	
<b>8</b>		Ph <sub>4</sub> PBr (2.5)	180	24	72 (100)	<b>57</b>
		CNC (2.5)	180	24	63 (100)	
		(Et <sub>2</sub> N) <sub>3</sub> PNPPh <sub>3</sub> Br (2.5)	180	24	54 (100)	
		(Et <sub>2</sub> N) <sub>4</sub> PBr (2)	165	20	69 (88)	
<b>10</b>	Sulpholane (150)	-	200	9	30	<b>57</b>
	Sulpholane (150)	Ph <sub>4</sub> PBr (2.0)	180	7	(5)	
	Sulpholane (10)	CNC (1.5)	175	24	5	
	Me <sub>2</sub> SO (10)	CNC (1.5)	175	24	20	
	Sulpholane (100)	CNC (1.5)	175	24	54	
	Sulpholane (100)	CNC (1.5)	190	15	49	
	DMI (100)	CNC (1.5)	180	24	75	
	DMI (100)	(Et <sub>2</sub> N) <sub>3</sub> PNPPh <sub>3</sub> Br (1.5)	180	24	(30)	

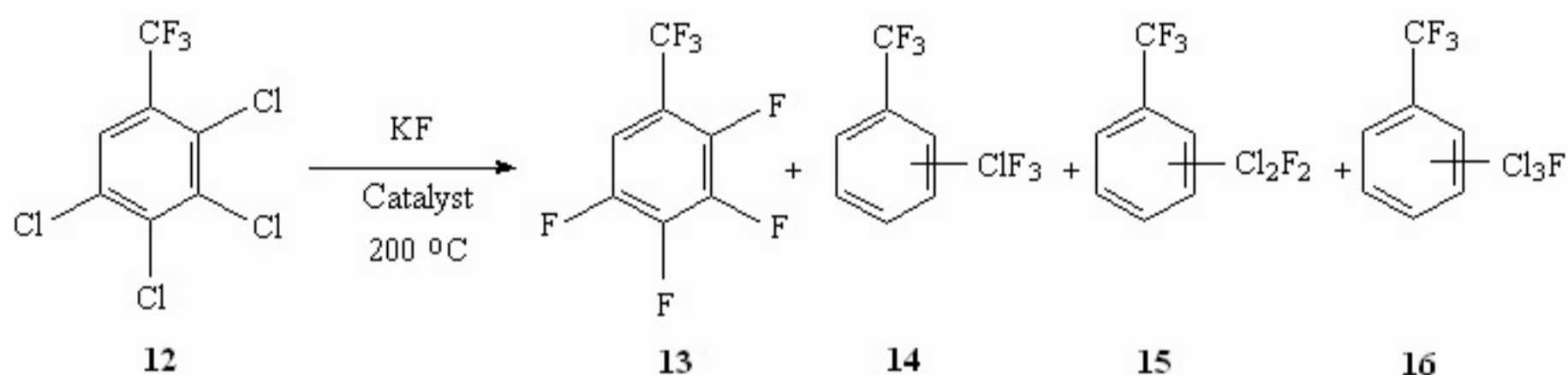
The presence of two chlorine atoms in benzene ring produces, as a rule, difluoroderivatives, for example in the case of 2,6-dichlorobenzaldehyde (table 7) they obtain 2,6-difluorobenzaldehyde, which is an important product in herbicide production [57].



The same result is obtained also for 2,4-dichlorobenzoic acid dichloranhydride (table 6) [57].



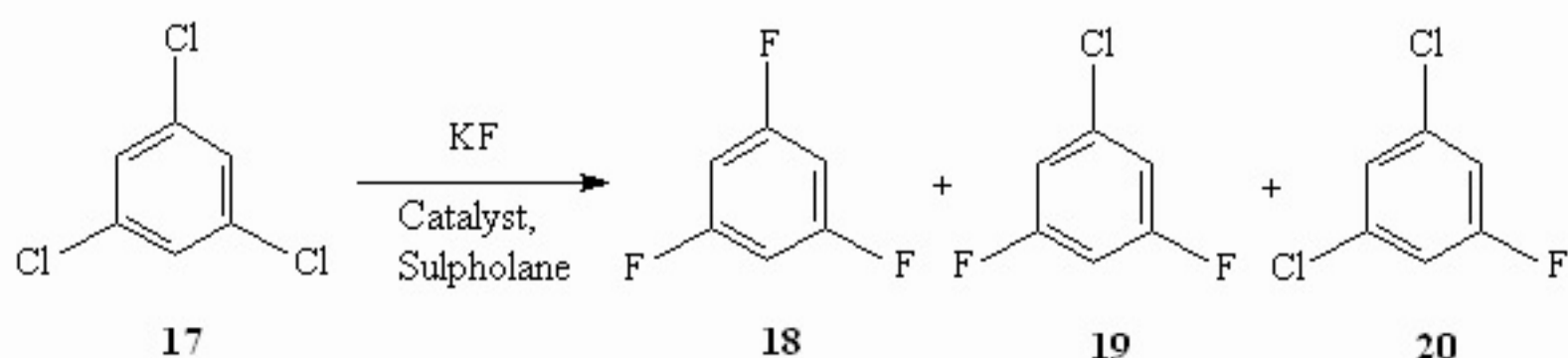
We can observe a more complicated picture at fluorinating of tetrachlorobenzotrifluoride **12**. In this depending on the character of catalysts used we see a different degree of fluorination (table 8) [57].



**Table 8.** Synthesis of Tetrafluorobenzotrifluoride out of Tetrachlorobenzotrifluoride

Catalysts (mol. %)	T, °C	Yield, %				
		12	13	14	15	16
CTC (1.5)	200	0	0	5	66	29
PNC (1.5)	200	0	1	24	70	5
Ph <sub>4</sub> PBr (1.5)	200	19	0	0	19	62
(Et <sub>2</sub> N) <sub>3</sub> PNPPh <sub>3</sub> Br (1.5)	200	4	0	4	54	38
CNC (1.9)	200	0	84	17	0	0
PNC (1.9)	200	0	67	33	0	0
Ph <sub>4</sub> PBr (1.9)	200	0	1	6	78	14
(Et <sub>2</sub> N) <sub>3</sub> PNNPh <sub>3</sub> Br (1.9)	200	0	9	51	40	0

Effective catalysts have been found for production of 1,3,5-trifluorobenzene by influencing of potassium flu on 1,3,5-trichlorobenzene (table 9) [57].



**Table 9.** Obtaining of 1,3,5-trifluorobenzene by Influencing 1,3,5-trichlorobenzene Using Potassium Fluoride in the Presence of Various Catalysts

Catalysts (mol. %)	T, °C	Yield, %				
		17	18	19	20	Residue
CTC (5)	230	1	18	61	20	1
(Me <sub>2</sub> N) <sub>3</sub> PNPPh <sub>3</sub> Br (5)	230	1	15	60	20	5
CNC (5)	230	0	87	8	1	4
(Me <sub>2</sub> N) <sub>3</sub> PNPPh <sub>3</sub> Br (5)	230	0	46	46	2	6

Thus, 2,3,4-trifluoro-5-chloro-1-trifluoromethylbenzene is obtained with the yield of 85% at heating of 2-trichloro-1-trifluoromethylbenzene in sulpholane in the autoclave at 210 °C and pressure of 2.2 bar in the presence of Et<sub>4</sub>PBr [58]. The effectiveness of the process is increasing when using finely dispersed anhydrous potassium fluoride and tetrakis(diethylamido)-phosphonium bromide (R<sub>2</sub>N)<sub>4</sub>P<sup>+</sup> · Hal<sup>-</sup> [59,60].

Taking into account the commercial value of hexafluorobenzene, the majority of information regarding its obtaining has been published as patents, which sometimes hardly reveal the essence of the offered technologies. Nevertheless, the effectiveness of catalysts used to intensify the known hexafluorobenzene obtaining method is determined. In this case, we manage to soften the tough conditions of synthesis or to refuse the using of solvents. It is stated that quaternary ammonium salts, guanidine derivatives, quaternary phosphonium salts, krypton derivatives, crown ethers and polyesters [30,44-48,61,62] evince their most effectiveness as catalysts for interphase transfer.

Thus, the authors of work [30] showed, that potassium fluoride applied over calcium or barium fluoride reveals its high activity in the reaction of hexafluorobenzene fluorination. At that, the simultaneous using of potassium fluoride and **quaternary** phosphonium salt (for example, tetrakis(diethylamido)-phosphonium bromide) essentially increases the efficiency of chlorine for fluorine exchange process (table 2). As we can see from table 2, under conditions (230 °C, 42.5 h) the using of potassium fluoride dried by dispersion produces a summary yield of fluorination products of only 6%, while when using potassium fluoride, applied over calcium fluoride under analogous conditions produces the mixture of subsequent substitution of chlorine for fluorine products of high yield, though the main product is tetrachlorodifluorobenzene (46 %).

The substitution of chlorine for fluorine in hexachlorobenzene goes notably easier under the influence of potassium fluoride when using tetrakis(diethylamido)-phosphonium bromide as a catalyst for inter-phase transfer: at 230 °C in 42.5 h the reaction products contain 13.5% of chloropentafluorobenzene, 37% of dichlorotetrafluorobenzene and 45% of tetrachlorodifluorobenzene, which is the main product. Hexachlorobenzene fluorination process is going faster when using potassium fluoride, applied on CaF<sub>2</sub> (Table 2). The obtained results can be a consequence of simultaneous fluorination both on a solid surface and at organic phase and factors increasing the absorption of reagents on the solid surface (pressure, substrates nature) will lead to raising the rate of exchange.

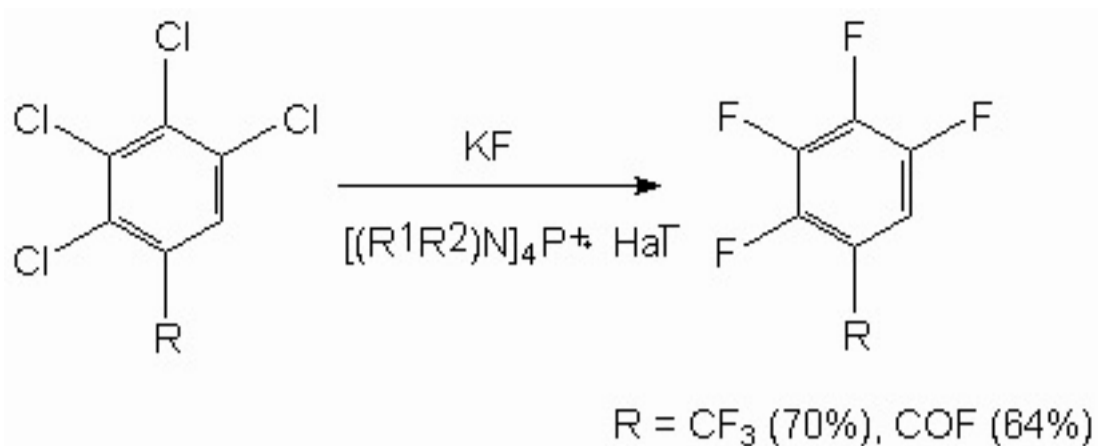
N,N',N''-Hexasubstituted guanidinium chlorides proved as effective ones at obtaining hexafluorobenzene [59]. Thus, hexafluorobenzene was obtained out of hexachlorobenzene and KF with the yield of 90% at 160-170 °C in the presence of this catalyst.

We used ammonium salts like [(RR'N)<sub>2</sub>CN<sup>2</sup>R<sup>3</sup>]<sup>+</sup> · X<sup>-</sup> (where R-R<sup>3</sup> = alkyl C<sub>1-7</sub>, cycloalkyl C<sub>5-8</sub>) like hexaethylguanidinium chloride [64] as catalysts. Carrying out reaction at 160-170 °C produces the mixture containing 91% of hexafluorobenzene, and 9% of partly fluorinated fluorochlorobenzenes. The overall yield of hexafluorobenzene is 88.4%.

The quaternary phosphonium salts are more effective, what caused their wider use and research of exchange processes involving them. Thus, pentafluoro-containing benzene derivatives like C<sub>6</sub>F<sub>n</sub>X<sub>6-n</sub> (X = F, Cl, CF<sub>3</sub>, CN; n = 1-5) are obtained by heating of corresponding halogen-containing aromatic compounds with alkali metal fluoride in the liquid phase in the presence of tetrakis(diethylamido)phosphonium bromide in the medium of product starting substrate partial fluorination with simultaneous selection of target products at 150-200 °C [65]. In this case the technological process is becoming greatly simpler and the yield of polyfluoroaromatic compounds increases.

When carrying out a process of hexafluorobenzene fluorination using potassium fluoride in benzonitrile (catalyst amount is 12 g per 115 g of hexachlorobenzene) at 200 °C in 5.5 h we obtained a mixture, containing 24.4% of hexafluorobenzene, 39.9% of pentafluorochlorobenzene, 21% of tetrafluorodichlorobenzenes' mixture and 8% of trifluorotrchlorobenzenes [60]. The effectiveness of this catalysts was proven by authors of works [55,66] in the example of hexachlorobenzene and partly fluorinated chlorobenzenes.

We should note, that the presence of several chlorine atoms in benzene ring is not an obstacle for exchange reaction taking place [55].



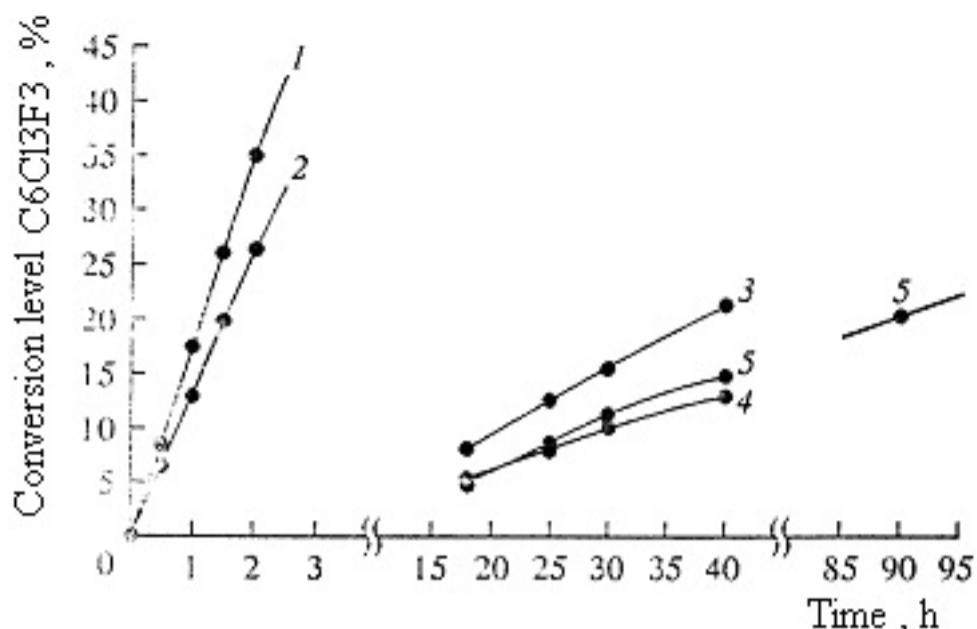
Catalysts can take part in acceleration reaction of fluorodechlorination of chloroaromatic substrates at different process stages. At first, they can increase KF concentration in liquid phase, secondly, lowering the energy of reaction activation because of inter-phase  $\sigma$ -complex participation in stabilization, they can also lead to increase of catalytic system activity [59]. Adding to such catalytic system promoters, representing compound heterocyclic cycle and aromatic row, ethers, substituted amides of organic acids etc, promotes the rate of chlorine exchange for fluorine and increasing the yield of final products [62]. Under these conditions the compounds with the common formula C<sub>6</sub>F<sub>4</sub>XY (where X = F, Cl, CF<sub>3</sub>, CCl<sub>3</sub>, CN, COR; Y = F, H, Cl, CF<sub>3</sub>, CCl<sub>3</sub>, CN, COR) were obtained with their high yields [62]. The proportion of quaternary tetra-amidophosphonium salt is in the range between 10 and 5-20 : 1, and proportion of alkali metal fluoride and quaternary tetra-amidophosphonium salt is in the range ranging from 1000 : 1 to 10 : 1.

This method proved to be so effective, that American company "Albemarle" not only has patented this technology of synthesis of fluorinated aromatic compounds, allowing to raise the yield of final products at lower temperatures and at more moderated figures of pressure compare to usual method and to diminish the reaction period, but it also has built two plants producing several tons of hexafluorobenzene per year [67,68]. Different benzene derivatives are obtained based on it and first of all one of them is pentafluorobromobenzene..

When using tetraethylene glycol dimethyl ether and 18-crown-6 the catalysis effectiveness depends on substrate origin - the isomeric composition of trifluorotrchlorobenzenes, forming at using these catalysts without their using in sulpholane, at the same degrees of conversion is approximately the same [69] and in the case close to isomeric composition at fluorination of trifluorotrchlorobenzenes using potassium fluoride at 350 °C. authors consider, that speeding up of chlorine substitution for fluorine mainly occurs because of potassium fluoride nucleophilic reactivity rising.

Fluorodechlorination of tetrafluorodichlorobenzene by KF goes slowly (only traces of pentafluorochlorobenzene can be seen in 6 hours) in the presence of catalytic amounts of diglyme, tetraglyme or 18-crown-6 ester. [59] combination of hexaethylguanidinium chloride with polyesters results in noticeable growth of activity of catalytic system (conversion of tetrafluorodichlorobenzene doubles). We should notice, that such a growth of activity mentioned by the authors of work [30] when adding polyester to KF, applied on inert supporter (CaF<sub>2</sub>, BaF<sub>2</sub>) is due to fluorinating of hexafluorobenzene.

When using polyesters as catalysts the catalytic effect is explained from the point of view of increasing "active" ion-fluoride current concentration, which leads to speeding up of fluorodechlorination [59]. When using other catalysts the catalytic effect has some other origin and is connected not only with increasing concentration of "active" ion-fluoride, but also with great participation of these catalysts in stabilization of anionic  $\sigma$ -complexes, that results in decreasing of activation energy of fluorodechlorination reaction probably because of effective stabilization of inter-phase  $\sigma$ -complex [59].



**Fig.1.** The depending of conversion degree on reaction period (mole proportion  $C_6Cl_2F_4 : KF : catalyst$ , 1:1:1) [70]

- 1 - hexaethylguanidinium chloride
- 2 - tetra(diethylamido)phosphonium bromide
- 3 - 18-crown-6
- 4 - tetraethylene glycol dimethyl ether
- 5 - sulpholane (mass ratio  $C_6Cl_3F_3 : sulpholane$  , 1:1).

At the same time in case of catalysts of tetra(diethylamido)phosphonium bromide hexaethylguanidiniumchloride the difference of isomeric compositions compare to non-catalytic variant become noticeable as soon as conversion reaches 8.5%, and mainly developing at conversion of 20%. The apparent catalytic effect of these catalysts depends to a great extent on the origin of substrate. It can be connected with the scheme differences, taking place in every case of the processes [64].

According to up-to-date conceptions, the process of chlorine-aromatic compounds fluorodechlorination with potassium fluoride goes both on the surface of solid phase and  $\sigma$ -phase, directly bordering to potassium fluoride [16]. In both cases, the catalytic effect is connected with increase of reactivity of potassium fluoride. In first case as they think, it occurs because of more effective coordination of substrate on the surface of potassium fluoride and in the second one the reason of it is forming of incoherent ionic pairs between catalyst and ion-fluoride [64].

There are estimations, that poly-fluorochlorobenzenes' fluorodechlorination goes according to the addition-eliminating scheme with intermediate forming of anionic  $\sigma$ -complex [71]. At that it is considered, that the distinction of fluorination rate in catalytic and non-catalytic reactions can be not only due to catalyst's influence on increase of "active" ion-fluoride concentration but also to stabilization of corresponding  $\sigma$ -complex. At the same time participation of catalyst in speeding up of fluorodechlorination is limited by increasing of current concentration of "active" ion-fluoride, then catalytic effect will slightly depend on the substrate's nature. On the contrary, if catalyst is taking part in stabilization of intermediate  $\sigma$ -complex, we can expect, that in this case fluorodechlorination of more active substrates will accelerate more strongly, than of less active ones. The authors of work [72] studied the influence of different catalysts on the fluorodechlorination process of trifluorobenzenes and demonstrated, that maximum rate of trifluorotrchlorobenzenes' conversion is observed when used tetra(diethylamido)phosphonium bromide and hexaethylguanidiniumchloride as catalysts, and in sulpholane there is no catalyst at all the reaction goes in a least effective way (fig. 1). Besides that, the activity is decreasing in a row of isomers:  $1,2,4-F_3C_6Cl_3 > 1,2,3-F_3C_6Cl_3 > 1,3,5-F_3C_6Cl_3$  , i.e. in accordance with the influence of fluorine and chlorine atoms on stabilization of anionic  $\sigma$ -complex [71,72].

The information cited here allow us to establish the effect of applying catalysts at obtaining fluoroaromatic compounds by alkali metals fluorides influencing chlorine containing aromatic compounds.

## 2. Mechano-Chemical Hexafluorobenzene Obtaining Method

One of the ways to improve effectiveness of aromatic compounds fluorodechlorination process is accompanying by physical impact. Thus, using an example of reaction of nucleophilic chlorine replacement by fluorine we demonstrated a fundamental opportunity of carrying out a solid phase synthesis of fluoroaromatic compounds under conditions of mechanical and chemical activation.

Besides that, liquid phase fluorination processes can also be intensified by using fluorinating agent active beforehand. An important role here belongs to the preliminary preparation of potassium fluoride, its microdispersion and effective surface are particularly essential [70,73-75].

It was demonstrated, that when carrying out a reaction of hexachlorobenzene, octachloronaphthalene, pentachloropyridine and potassium fluoride or other fluorides of alkali and alkaline-earth metals and composites of a mixture containing (KF-CaF<sub>2</sub>, K<sub>2</sub>CO<sub>3</sub>-CaF<sub>2</sub> [76]) made on their base in planet-friction activation (planet mill APF-1M), which forwards mechanical and chemical activation of potassium fluoride (acceleration is 1000 g, activation period 20 min) at 350-500 °C we can obtain a mixture of chlorofluorobenzenes, octafluoronaphthalene and pentafluoropyridine respectively.

KF mechanical activation leads in acceleration of fluorination process and allows to increase yields of fluorinated benzenes or to shorten the period of reaction [70, 73]. Octafluoronaphthalene can be fluorinated easily, and hexachlorobenzene is a most difficult to be fluorinated. Thus, in 20 minutes activation period the rate of transformation of octachloronaphthalene into fluorine derivatives amounted to 75%, while in the same period rate of hexachlorobenzene amounted only to 22%. As the period of treatment was being increased we observe growth of conversion and substitution rate. The application of other metals fluorides in this reaction allowed to reach a conclusion, that activity of fluorinating agent was growing from lithium fluoride to cesium fluoride and calcium fluoride to barium fluoride. However in all the cases we observe a complicated composition of products.

The mixture was accumulated and rectified in an ordinary way to isolate individual products. This approach allows decreasing the process period, the excess of applied potassium fluoride and amount of waste products found, that in potassium fluoride-calcium fluoride systems and also potassium carbonate - calcium fluoride formation of mixed fluoride of KCaF<sub>3</sub>, occurs, which is a new fluorinating agent of a high activity. Thus, using composite mixture containing KF + CaF<sub>2</sub> the reaction of pentachloropyridine fluorination actually goes only in 10 minutes, while when using KF the products' yield is 35,8% in 120 min, and CaF<sub>2</sub> - 14.8%. Compare to potassium fluoride the mixed fluoride shows higher fluorinating ability not only during mechanical and chemical, particularly during liquid phase process of fluorination.

Using of fluorinating reagent (KF and KCaF<sub>3</sub>) allowed to obtain 3-chlorine-4-fluoronitrobenzene out of dichloronitrobenzene at 150 °C in the sulfolane medium [73].