

Calculation of Fluoroalkylamines Transport Coefficients Used in Agriculture and Medicine in the Context of Plasma Incineration

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Abstract Knowledge of FluoroalkylAmines-air mixtures thermal plasmas transport coefficients is important for plasma performance characterization and transport phenomena modelization in the plasma. In this work, these FluoroalkylAmines-air mixture plasmas transport properties are calculated in a temperature range of 1000 K to 20 000 K at atmospheric pressure and local thermodynamic equilibrium (LTE). It appears from these evaluations that the percentage of air in the mixture has neglected influence on the electrical conductivity of the plasmas. For temperatures higher than 13 000 K, we have noticed a decrease of the thermal conductivity and the dynamic viscosity with the percentage of air in the mixture plasmas. The different high levels observed on the thermal conductivity graph is conform to the dissociation reactions of molecules and ionization reactions of atoms.

Keywords: fluoroalkylamines, incineration, plasma, transport coefficients

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1. Introduction

The use of thermal plasmas, particularly through specific plasma's torches for the destruction of new toxic waste, is promising [1]. To better understand the highly reactivity of these plasma systems many theoretical and experimental studies has been carried out on electrical arc and thermal plasmas [2-11]. In developing countries, we are noticing a proliferation of waste storage areas and open-air waste burning area. These wastes are most of the time from developed countries [12]. These practices have a lot of consequences such as air, soil and water pollution. These pollutions have enormous consequences on human and animal health. Unfortunately, the chemical industries produce each year new active ingredients as fluorinated organic element. These elements as FluoroalkylAmines or pyrimidine-based molecules are promoting in the field of agriculture (pesticides and herbicides) and pharmacology (antibiotics) [13]. The massive use of these molecules will result by increment of waste containing this type of molecules. Plasma incineration is a waste treatment method that offers environmental advantages than traditional methods. Understanding the behavior of Fluoroalkylamines during this process is very important to assess their future and environmental impact. The goal of

this work is to study the air influence on the FluoroAlkylamines plasmas transport coefficient at atmospheric pressure and at local thermodynamic equilibrium (LTE) in the temperature range of 1000 K to 20 000 K. This temperature range covers the temperatures measured in plasma torches. In this study, we consider only the gas step. We consider that the air is composed of 20% oxygen and 80% nitrogen, and that the different percentages are volumic percentages. The calculations are carried out at atmospheric pressure. In order to study test cases, we have choosed as a type of FluoroalkylAmines, TrifluoroethylAmine ($C_2H_4F_3N$) and NonafluoropentylAmine ($C_5H_4F_9N$).

2. Transport Coefficients

The transport coefficients are essential data for the modelization of transport phenomena present in thermal plasmas. They are got by solving the Boltzmann integral-differential equation according to the Chapman-Enskog method adapted to ionized gases. Chapman [14-16] shows that the expressions of the transport coefficients depend on other functions called collision integrals, the interaction potential used to characterize the collision between two particles i and j, and the order of approximation chosen for the development of the Sonine polynomials. This level of

approximation fixes the number of pairs (l, s) to be considered in the calculation of the integrals of collision. We consider that our different plasmas are composed of fifty-five ($v = 55$) chemical species which are : electrons : e^- ; monoatomic species: C , C^+ , C^{2+} , C^- , F , F^+ , F^- , H , H^+ , H^- , N , N^+ , N^{2+} , N^- , O , O^+ , O^{2+} , O^- ; diatomic species: C_2 , F_2 , H_2 , N_2 , O_2 , CF , CH , CN , NF , NH , CO , NO , OH , HF , C_2^+ , H_2^+ , N_2^+ , O_2^+ , NO^+ , CF^+ , CH^+ , CN^+ , NH^+ , CO^+ , C_2^- , CN^- ; polyatomic species: CO_2 , NO_2 , NO_3 , CF_2 , CF_3 , CH_4 , C_2F , C_2F_2 , NH_3 , HCN .

2.1. Electrical Conductivity Coefficient

The transfer of electrical charges is mainly due to electrons because their mobility is higher than ions mobility. Thus, the electrical conductivity is written from the third-order approximation of the Chapman-Enskog method as [17,18]:

$$\sigma = \frac{3}{2} e^2 n_1^2 \left(\frac{2\pi}{m_1 kT} \right)^{1/2} \frac{\begin{vmatrix} q^{11} & q^{12} \\ q^{21} & q^{22} \end{vmatrix}}{\begin{vmatrix} q^{00} & q^{01} & q^{02} \\ q^{10} & q^{11} & q^{12} \\ q^{20} & q^{21} & q^{22} \end{vmatrix}} \quad (1)$$

with n_1 and m_1 the numerical density and electrons mass, k the Boltzmann constant. q^{ij} depends on the numerical density and the integrals of collisions between particles.

2.2. Coefficient of Viscosity

It is related to the transportation of movement quantity and depends on a first approximation, only on collisions between heavy particles. It is written in as [19]:

$$\eta = - \frac{\begin{vmatrix} H_{11} & \dots & H_{1v} & X_1 \\ \dots & \dots & \dots & \dots \\ H_{v1} & \dots & H_{vv} & X_v \\ X_1 & \dots & X_v & 0 \end{vmatrix}}{\begin{vmatrix} H_{11} & \dots & H_{1v} \\ \dots & \dots & \dots \\ H_{v1} & \dots & H_{vv} \end{vmatrix}} \quad (2)$$

with :

$$H_{ii} = \frac{X_i^2}{\eta_i} + \sum_{\substack{k=1 \\ k \neq i}}^v \frac{2X_i X_k}{\eta_{ik}} \frac{M_i M_k}{(M_i + M_k)^2} \left(\frac{5}{3A_{ik}^*} + \frac{M_k}{M_i} \right) \quad (3)$$

$$H_{ij} = \frac{2X_i X_j}{\eta_{ij}} \frac{M_i M_j}{(M_i + M_j)^2} \left(\frac{5}{3A_{ij}^*} - 1 \right) \quad (4)$$

$$A_{ij}^* = \frac{\Omega_{ij}^{(2,2)}}{\Omega_{ij}^{(1,1)}} \quad (5)$$

$$\eta_{ij} = \frac{5}{16} \frac{1}{\Omega_{ij}^{(2,2)}} \sqrt{\frac{KT}{N_A \pi}} \sqrt{\frac{2M_i M_j}{M_i + M_j}} \quad (6)$$

$\Omega_{ij}^{(l,s)}$ which is the particles collision integral i and j , X_i and M_i are the mole fraction and molar mass of chemical species i , N_A is Avogadro number.

2.3. Thermal Conductivity Coefficient

The thermal conductivity of a plasma represents its capacity to transfer heat. It is the sum of the translational thermal conductivities of heavy particles, electrons, reaction and internal:

$$\lambda_{tot} = \lambda_{tr}^h + \lambda_{tr}^e + \lambda_{reac} + \lambda_{int} \quad (7)$$

2.3.1. Thermal Conductivity of Heavy Species

The expression for the translational thermal conductivity of heavy particles is got by a second-order approximation of the Chapman-Enskog method [20]:

$$\lambda_{tr}^h = 4 \frac{\begin{vmatrix} L_{11} & \dots & L_{1v} & X_1 \\ \dots & L_{ii} & \dots & \dots \\ L_{v1} & \dots & L_{vv} & \dots \\ X_1 & \dots & X_v & 0 \end{vmatrix}}{\begin{vmatrix} L_{11} & \dots & L_{1v} \\ \dots & L_{ii} & \dots \\ L_{v1} & \dots & L_{vv} \end{vmatrix}} \quad (8)$$

The coefficients L_{ij} are given by Muckenfuss [20] for a medium composed of v species.

2.3.2. Thermal Conductivity of Electrons

It given by Devoto [18,21] to the third order approximation in the Chapman-Enskog method as follows:

$$\lambda_{tr}^e = \frac{75}{8} n_1^2 k \left(\frac{2\pi kT}{m_1} \right)^{1/2} \frac{q^{22}}{q^{11} q^{22} - (q^{12})^2} \quad (9)$$

The coefficients q^{ij} are the same as those used in the calculation of electrical conductivity.

2.3.3. Thermal Conductivity of Reaction

For a gas step containing v chemical species constituted from p elements, there are $N = v - p$ possible chemical reactions. The thermal conductivity of the reaction is then expressed at the first order of the Chapman-Enskog method by [22,23]:

$$\lambda_{\text{reac}} = -\frac{1}{RT^2} \frac{\begin{vmatrix} A_{11} & \dots & A_{1v} & \Delta H_1 \\ \dots & \dots & \dots & \dots \\ A_{v1} & \dots & A_{vv} & \Delta H_v \\ \Delta H_1 & \dots & \Delta H_v & 0 \end{vmatrix}}{\begin{vmatrix} A_{11} & \dots & A_{1v} \\ \dots & \dots & \dots \\ A_{v1} & \dots & A_{vv} \end{vmatrix}} \quad (10)$$

with:

$$\begin{cases} A_{ij} = A_{ji} = \sum_{k=1}^{v-1} \sum_{l=k+1}^v \frac{RT}{PD_{kl}} X_k X_l \left(\frac{a_{ik}}{X_k} - \frac{a_{il}}{X_l} \right) \left(\frac{a_{jk}}{X_k} - \frac{a_{jl}}{X_l} \right) \\ D_{ij} = \frac{2,628 \cdot 10^{-2}}{P} T^{3/2} \frac{(M_i + M_j)^{1/2}}{\Omega_{i,j}^{(1,1)}} \end{cases}$$

P is the pressure of the area, D_{ij} is the binary diffusion coefficient, R is the perfect gas constant, and ΔH_i is the enthalpy change for a reaction i .

We considered forty-nine (49) independent chemical reactions in the following FluoroalkylAmines and air mixture plasmas:

$C_2 \rightarrow 2C$	$HF \rightarrow H+F$	$C_2F \rightarrow C_2+F$	$H_2 \rightarrow H_2^+ + e^-$	$F+e^- \rightarrow F^-$
$F_2 \rightarrow 2F$	$CO \rightarrow C+O$	$C_2F_2 \rightarrow C_2F+F$	$N_2 \rightarrow N_2^+ + e^-$	$H+e^- \rightarrow H^-$
$H_2 \rightarrow 2H$	$NO \rightarrow N+O$	$NH_3 \rightarrow N+3H$	$O_2 \rightarrow O_2^+ + e^-$	$N+e^- \rightarrow N^-$
$N_2 \rightarrow 2N$	$OH \rightarrow O+H$	$HCN \rightarrow CN+H$	$CF \rightarrow CF^+ + e^-$	$O+e^- \rightarrow O^-$
$O_2 \rightarrow 2O$	$CO_2 \rightarrow CO+O$	$C \rightarrow C^+ + e^-$	$CH \rightarrow CH^+ + e^-$	$C_2+e^- \rightarrow C_2^-$
$CF \rightarrow C+F$	$NO_2 \rightarrow NO+O$	$F \rightarrow F^+ + e^-$	$CN \rightarrow CN^+ + e^-$	$CN+e^- \rightarrow CN^-$
$CH \rightarrow C+H$	$NO_3 \rightarrow NO_2+O$	$H \rightarrow H^+ + e^-$	$NH \rightarrow NH^+ + e^-$	$O^+ \rightarrow O^{++} + e^-$
$CN \rightarrow C+N$	$CF_2 \rightarrow CF+F$	$N \rightarrow N^+ + e^-$	$NO \rightarrow NO^+ + e^-$	$N^+ \rightarrow N^{++} + e^-$
$NF \rightarrow N+F$	$CF_3 \rightarrow CF_2+F$	$O \rightarrow O^+ + e^-$	$CO \rightarrow CO^+ + e^-$	$C^+ \rightarrow C^{++} + e^-$
$NH \rightarrow N+H$	$CH_4 \rightarrow C+4H$	$C_2 \rightarrow C_2^+ + e^-$	$C+e^- \rightarrow C^-$	

2.3.4. Internal Thermal Conductivity

According to Hirschfelder [19] and by extension of Eucken's theory, formulated for a pure gas, Yun et al [24] propose an analytical expression, at order 1, of the internal thermal conductivity which is written:

$$\lambda_{\text{int}} = \sum_{i=1}^v \frac{PD_{ii}}{RT} \left(C_{pi} - \frac{5}{2} R \right) \frac{D_{ii}}{1 + \sum_{j \neq i}^v \frac{D_{ij}}{D_{ii}} \frac{X_j}{X_i}} \quad (11)$$

with the specific heat of the species i given by:

$$C_{pi} = \frac{\partial \Delta H_i}{\partial T} = \frac{\partial}{\partial T} \left(\frac{5}{2} RT + RT^2 \frac{\partial \ln \ln(Q_{\text{int}})_i}{\partial T} \right)$$

3. Collision Integrals and Interaction Potential

3.1. Neutral-Neutral Interactions

We used the parameters of the Lennard-Jones potential published by André et al [23], Cressault et al [25] and Yang et al [4]. Knowing these parameters, the collision integrals are determined using the empirical formula of Neufeld et al [26]:

$$\Omega_{ij}^{(l,s)} = r_0^2 \left[\frac{A}{T^{*B}} + \frac{C}{\exp(DT^*)} + \frac{E}{\exp(FT^*)} + \frac{G}{\exp(HT^*)} + RT^{*B} \sin \sin(ST^{*W} - P) \right] \quad (12)$$

with $T^* = \frac{kT}{\varepsilon_{ij}}$ and the values of A to W are tabulated as a function of (l, s) [26].

Table 1. Lennard Johns parameters used in our calculation

Chemical species		sigma (Å)	Eps (K/particle)	References
C	C	3	100	[23]
F	F	2.968	112.6	[25]
H	H	2.6	40	[23]
N	N	2.98	119	[23]
O	O	2.8	117	[23]
C ₂	C ₂	3.913	78.8	[25]
F ₂	F ₂	3.357	112.6	[25]
H ₂	H ₂	2.968	37.3	[23]
N ₂	N ₂	3.68	91.5	[23]
O ₂	O ₂	3.499	100	[23]
CF	CF	3.635	94.2	[25]
CN	CN	3.856	75	[25]
CO	CO	3.60	100	[23]
NO	NO	3.492	116.7	[25]
CO ₂	CO ₂	4	200	[23]
NO ₂	NO ₂	4.06	97	[23]
NO ₃	NO ₃	3.462	114.81	[25]
CF ₂	CF ₂	3.977	108	[25]
CF ₃	CF ₃	4.3	134	[25]
CH ₄	CH ₄	3.8	144	[23]
C ₂ F ₂	C ₂ F ₂	3.635	94.2	[25]

We give the parameters of Lennard-Johns potential that we use and their sources in Table 1. For the unknown interaction potential, we use the following empirical combining laws [23]:

$$\varepsilon_{ij} = (\varepsilon_{ii} \varepsilon_{jj})^{1/2} \quad (13)$$

$$\sigma_{ij} = [(\sigma_{ii})^3 + (\sigma_{jj})^3 + \dots]^{1/3} \quad (14)$$

Table 2. Polarisability values of neutral species used in our calculation code

Chemical species	α (10^{-30} m ³)	References
C	1.76	[4, 23, 25]
F	0.557	[25]
H	0.666793	[23]
N	1.10	[23]
O	0.802	[4, 23]
C ₂	3.2	[23, 25]
F ₂	1.134	[4]
H ₂	0.8059	[23]
N ₂	1.7403	[23]
O ₂	1.5812	[23]
CF	2.053	[4]
CH	2.27	[23]
CN	2.1	[25]
NF	1.657	[25]
NH	0.75	[23]
CO	1.95	[23, 25]
NO	1.7	[23, 25]
OH	1.47	[23]
CO ₂	2.911	[23]
NO ₂	3.02	[23, 25]
NO ₃	3.506	[25]
CF ₂	2.449	[4]
CF ₃	2.631	[4]
CH ₄	2.593	[23]
C ₂ F	4.649	[4]
C ₂ F ₂	3.542	[4]
NH ₃	2.2	[23]
HF	0.2204	[25]
HCN	2.525	[23]

3.2. Electrons-Neutral and Ion-Neutral Interactions

We used the polarizability model given by relation (13).

$$\Omega_{ij}^{(l,s)} = \left(\frac{Z^2 e^2 \alpha}{2\pi \epsilon_0 kT} \right)^{1/2} \left[\frac{\Gamma(s + 3/2)}{(s+2)!} \cdot \frac{A_{(4)}^{(l)}}{2l+1 - (-1)^l} \right] \quad (15)$$

with α is the polarizability of the neutral particle, Z the charge number of the charged particle, $A_{(4)}^{(l)}$ are parameters given in [27].

3.3. Charged-Charged Interactions

The interactions between the charged particles are characterized by the screened Coulomb potential at the Debye length whose collision integrals are tabulated as a function of the reduced temperature in the tables of Mason [28] and Devoto [29].

$$Q_{ij}^{(1,s)} = \frac{4\pi}{s(s+1)} \left(\frac{Z_i Z_j e^2}{2kT} \right)^2 \left[\ln \ln \left(\frac{4\lambda_D kT}{Z_i Z_j e^2} \right) - \frac{1}{2} - 2\gamma + \psi(s) \right] \quad (16)$$

$$Q_{ij}^{(2,s)} = \frac{12\pi}{s(s+1)} \left(\frac{Z_i Z_j e^2}{2kT} \right)^2 \left[\ln \ln \left(\frac{4\lambda_D kT}{Z_i Z_j e^2} \right) - \frac{1}{2} - 2\gamma + \psi(s) \right] \quad (17)$$

with e the elementary charge, Z_i the charge number of particle i , r the distance between the two particles, λ_D the Debye

length, $\psi(s) = \sum_{n=1}^{s-1} \left(\frac{1}{n} \right)$, $\psi(1) = 0$, γ is the Euler constant.

4. Comparaisons

In order to validate our calculation code, we have compared our transportation coefficients results in dry air plasma case to atmospheric pressure with those of Capitelli et al [30], Boulos et al [31] and P. André [8]. Our electrical conductivity, thermal conductivity and dynamic viscosity results are in good agreement with those of Capitelli et al, with a low difference of 4%. For the calculation of electrical conductivity, our results are almost similar to those of P. André and Boulos et al, with a difference of 8% for the temperatures around 6000 K and 8000 K. There is a difference between our results for thermal conductivity and dynamic viscosity and those of P. André and Boulos et al. This difference is more remarkable at temperatures around 15,000 K. The gap between our results and those of other authors can be explained by the choice of interaction potential as Hulbert Hirshfelder, Lennard Johns, effective potentials... and the way to obtain collision integral. That is to say numerical integration or approximative formulations. Furthermore, the way of Debye length calculation taking ions and electrons or only electrons into account can play a major role for the charge-charge interactions.

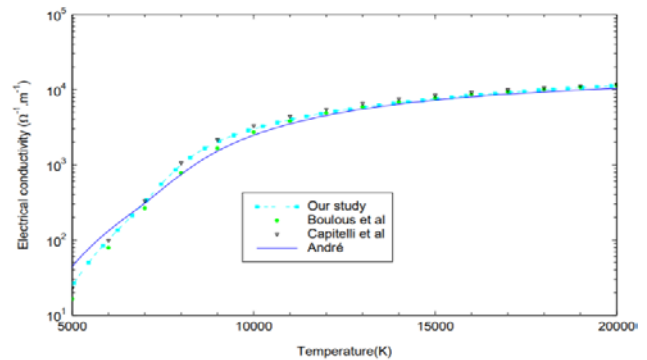


Figure 1. Comparison of the electrical conductivity results of our study with those of André [8], Capitelli et al [30] and Boulos et al [31]

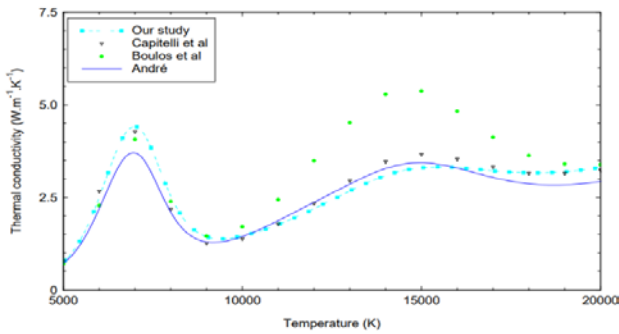


Figure 2. Comparison of the thermal conductivity results of our study with those of André [8], Capitelli et al [30] and Boulos et al [31]

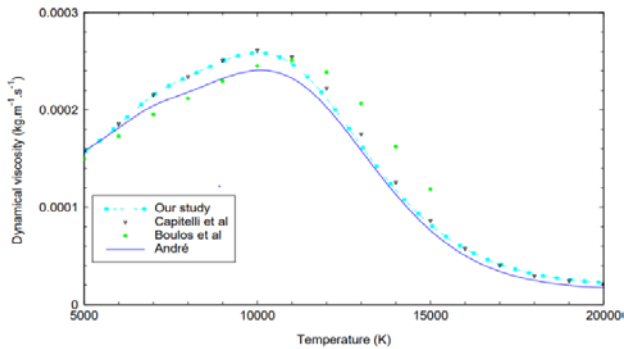


Figure 3. Comparison of the dynamical viscosity results of our study with those of André [8], Capitelli et al [30] and Boulos et al [31]

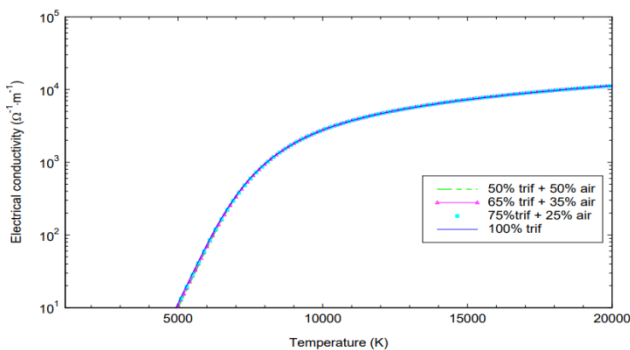


Figure 4. Electrical conductivity evolution of plasma versus temperature at atmospheric pressure

5. Results

5.1. Electrical Conductivity

The variations of electrical conductivity with temperature and percentage of air are shown in Figure 4 for a Trifluoroethylamine-air mixture plasma and Figure 5 for a Nonafluoropentylamine-air mixture plasma. The electrical conductivity curve is with those published in the literature: a sharp increase for temperatures below 10 000 K, followed by a quasi-linear and slightly increasing variation for temperatures above 10 000 K. Indeed, for temperatures below 10 000 K, electron-neutral collisions have a strong influence on the behavior of electrical conductivity. For these temperatures, the electron density varies quickly due to ionization phenomena. In the temperature range of 10 000 K and 20 000 K, the electrical conductivity reaches, close values for the most of mixtures. The collisions between charged particles governed by Coulombic

attraction become the majority resulting in a slightly increasing and quasi-linear electron density for a number of collisions constantly decreasing. On the other hand, it is generally observed that the percentage of air in the mixture has a practically negligible influence on the electrical conductivity of the mixture plasmas. This situation is explained by the fact that the percentage of air has a practically negligible influence on the electron number density in the mixture plasmas.

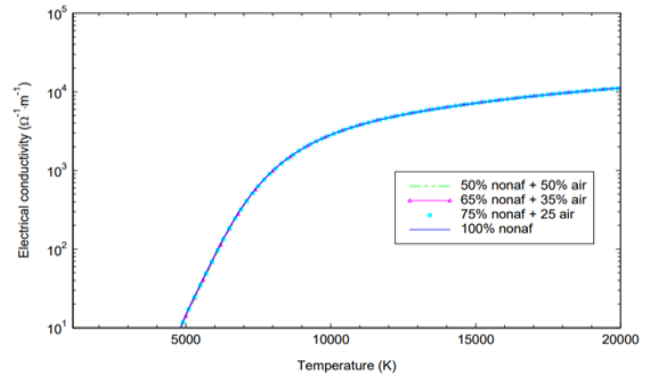


Figure 5. Electrical conductivity evolution of plasma versus temperature at atmospheric pressure

5.2. Thermal Conductivity

In figures 6 and 7, the total thermal conductivity curve and those of its four components of mixed plasmas (65%Trif + 35%Air) and (65%Nonaf + 35%Air) are represented. These figures give an idea of the contribution of each component on the total thermal conductivity. The observation of these figures shows that, over the whole range of temperatures, it is essentially the thermal conductivity of reaction, the translation of heavy species and electrons that contribute significantly to the total thermal conductivity. As for the internal component, it remains negligible over the entire temperature range. The thermal conductivity of reaction represents a very essential part of the total thermal conductivity. It characterizes the energy transport by dissociation and recombination of molecules or by ionization of species present in the plasma. But as the temperature increases, the component related to the translation of electrons increases. Figures 8 and 9 show the variation of the thermal conductivity of a Trifluoroethylamine-air mixture plasma and a Nonafluoropentylamine-air mixture plasma as a function of temperature and air percentage. The different peaks observed on the thermal conductivity curves correspond to the dissociation reactions of the molecules and the ionization reactions of the atoms. These are similar to those observed for the specific heat at constant pressure. The peaks appearing around 5000 K result from the dissociation of molecules (C_2H_4 , CH_4 , C_2H_2 , C_2F_2) and radicals (C_4N_2 , CH_2 , CH_3 , CF_3) (Fig.8 and 9). The following peaks located around 7000 K correspond to the dissociation of molecules (HCN , F_2) and radicals (C_2F , CF_2 , C_3 , C_2H). The following peaks located around 15000 K correspond to the dissociation of molecules (HF , C_2 , N_2), radicals (CF , CN , CH , CO) and the ionization of species such as (F , H , N , C , O , N^+). We notice that the peak located around 7000 K increases with the percentage of air in the mixture.

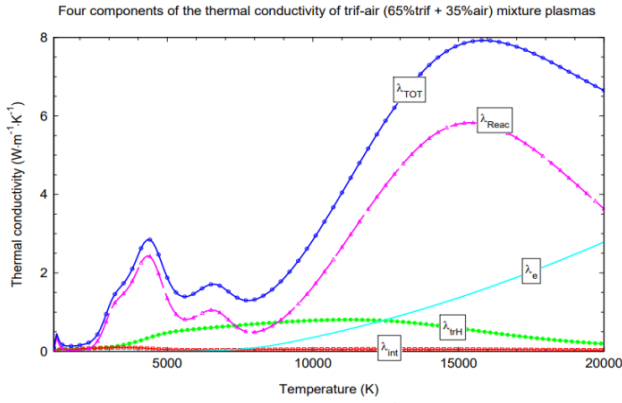


Figure 6. Total thermal conductivity and its four components evolution of plasma versus temperature at atmospheric pressure

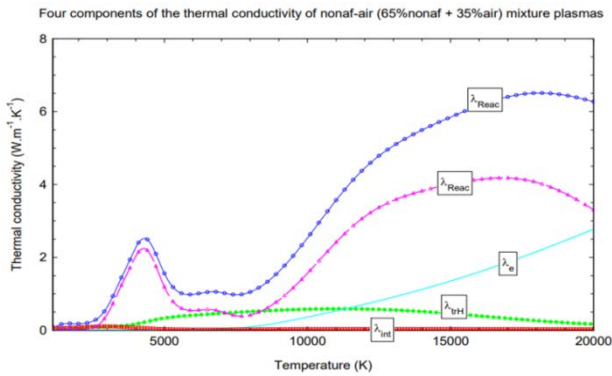


Figure 7. Total thermal conductivity and its four components evolution of plasma versus temperature at atmospheric pressure

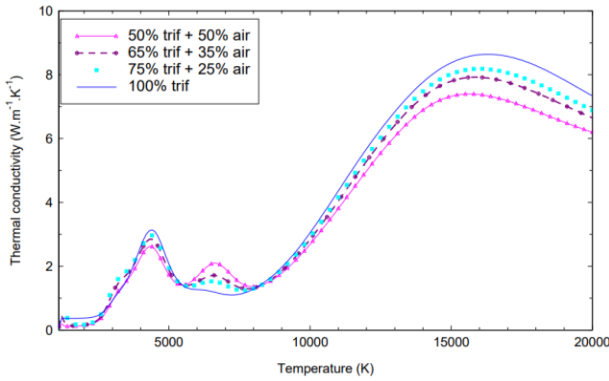


Figure 8. Thermal conductivity evolution of plasma versus temperature at atmospheric pressure

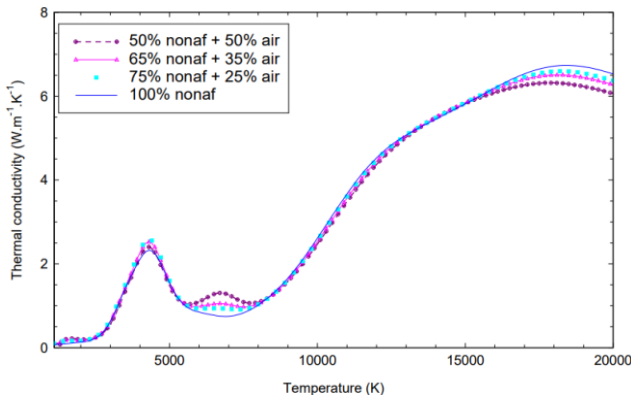


Figure 9. Thermal conductivity evolution of plasma versus temperature at atmospheric pressure

5.3. Dynamical Viscosity

We have represented in figures 10 and 11 the viscosity variation of a Trifluoroethylamine-air mixture plasma and a Nonafluoropentylamine-air mixture plasma as a function of temperature and air percentage. We find the characteristic shape of the amic viscosity encountered in the literature. It's say, a "bell-shaped" curve presenting a maximum (sometimes several maxima) located at temperatures corresponding to the phenomenon of first ionization. Therefore, the viscosity reflects the transition from a neutral or partialionized plasma to a fully ionized plasma. We notice that the maximum of viscosity corresponds to a temperature located around 10 000 K. Beyond this temperature, we observe a rapid decreasing related to the progressive disappearance of neutral particles (molecules, atoms). In the range of temperatures between 1000 K and 10 000 K, the viscosity of the plasma is dominated by neutral-neutral interactions. Then by ion-ion interactions for temperatures above 10 000 K. In this last range of temperatures ($T > 10\,000\text{ K}$), the viscosity decreases because the ions become the majority in the plasma. This decrease can also be explained by the decrease of the binary scattering terms proportional to $\bar{\Omega}_{ij}^{(2,2)}$ and also by interactions taking place more and more between charged particles (coulombic forces) whose values are significantly higher. The observation of these figures shows that:

- for temperatures below 5000 K, the viscosity of nonafluoropentylamine-air mixture plasma is higher than trifluoroethylamine plasma. But the viscosity of the trifluoroethylamine-air mixture plasma is lower than trifluoroethylamine. This could be explained by the fact that the most viscous plasmas are those containing a high percentage of fluorine and carbon;
- in the temperature range of 5000 K and 13 000 K, the viscosity increases with the percentage of air in the mixture. This increase is explained by the dissociation of the N_2 molecules [32];
- for temperatures below 13 000 K, the viscosity decreases with the percentage of air in the mixture.

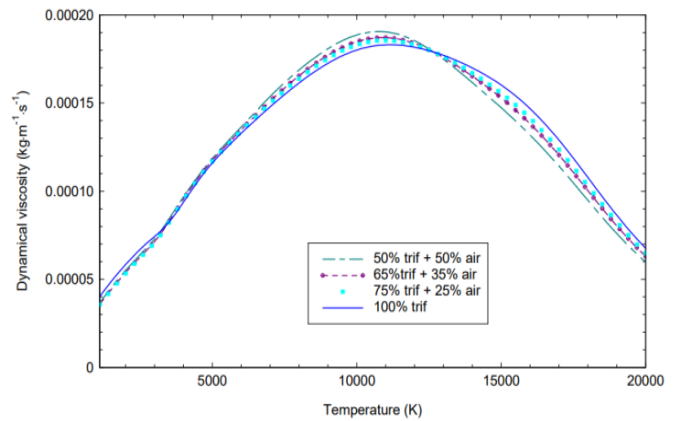


Figure 10. Dynamical viscosity evolution of plasma versus temperature at atmospheric pressure

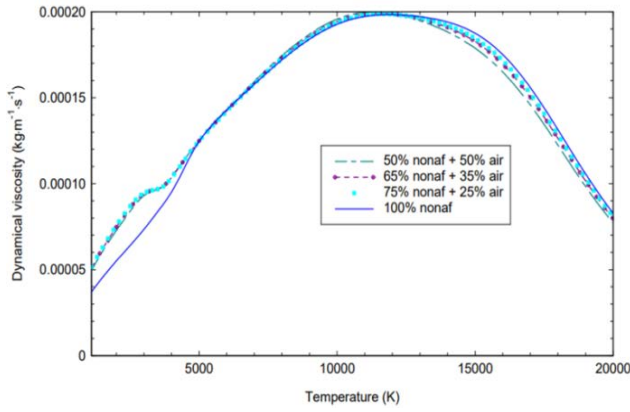


Figure 11. Dynamical viscosity evolution of plasma versus temperature at atmospheric pressure

3. Conclusion

The results of the calculation of the transport coefficients show that the dynamic viscosities of the plasmas from considered mixtures have similar evolutions over the whole temperature range. It is only found that, for temperatures below 5000 K, the viscosity of the nonafluoropentylamine-air mixture plasma is higher than that of the nonafluoropentylamine plasma. But the viscosity of trifluoroethylamine-air mixture plasma is lower than the one of trifluoroethylamine. This could be explained by the fact that the most viscous plasmas are those containing a high percentage of fluorine and carbon. The electrical conductivities also show similar trends. A strong increase is observed for temperatures below 10 000 K, followed by a quasi-linear and slightly increasing variation for temperatures above 10 000 K. In general, the percentage of air in the mixture has an almost negligible influence on the electrical conductivities of the mixed plasmas. The different peaks observed on the thermal conductivity curves correspond to the dissociation reactions of molecules and the ionization reactions of atoms. These are similar to those observed for the specific heat at constant pressure. Theoretical calculations provide an initial approach to estimate the transport coefficients. These latter are necessary to estimate the energy provided by a plasma torch necessary to destroy the molecules of FluoroAlkylamines. The electrical conductivity is related to the power supply. The thermal conductivity to the cooling of the plasma and the viscosity to the time that the plasma stays in the torch. Furthermore, we have shown by a comparison with other authors an accurate approach for potential is needed to get valuable transport coefficients.

4. Annexe

$$q^{00} = 8\pi n_1 \sum_{j=2}^v n_j \Omega_{1j}^{-(1,1)}$$

$$q^{01} = 8\pi n_1 \sum_{j=2}^v n_j \left(\frac{5}{2} \Omega_{1j}^{-(1,1)} - 3 \Omega_{1j}^{-(1,2)} \right)$$

$$q^{11} = 8\sqrt{2} n_1^2 Q_{11}^{-(2,2)} + 8 \sum_{j=2}^v n_1 n_j \left[\frac{25}{4} Q_{1j}^{-(1,1)} - 15 Q_{1j}^{-(1,2)} + 12 Q_{1j}^{-(1,3)} \right]$$

$$q^{02} = 8\pi n_1 \sum_{j=2}^v n_j \left(\frac{35}{8} \Omega_{1j}^{-(1,1)} - \frac{21}{2} \Omega_{1j}^{-(1,2)} + 6 \Omega_{1j}^{-(1,3)} \right)$$

$$q^{12} = q^{21} = 8\sqrt{2} n_1^2 \left[\frac{7}{4} Q_{11}^{-(2,2)} - 2 Q_{11}^{-(2,3)} \right] + 8 \sum_{j=2}^v n_1 n_j \left[\frac{175}{16} Q_{1j}^{-(1,1)} - \frac{315}{8} Q_{1j}^{-(1,2)} + 57 Q_{1j}^{-(1,3)} - 30 Q_{1j}^{-(1,4)} \right]$$

$$q^{22} = 8\sqrt{2} n_1^2 \left[\frac{77}{16} Q_{11}^{-(2,2)} - 7 Q_{11}^{-(2,3)} + 5 Q_{11}^{-(2,4)} \right] + 8 \sum_{j=2}^v n_1 n_j \left[\frac{1225}{64} Q_{1j}^{-(1,1)} - \frac{735}{8} Q_{1j}^{-(1,2)} + \frac{399}{2} Q_{1j}^{-(1,3)} - 210 Q_{1j}^{-(1,4)} + 90 Q_{1j}^{-(1,5)} \right]$$

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