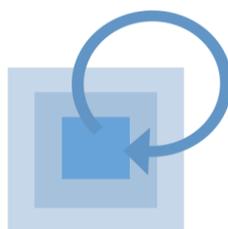




Project acronym: **MATCHIT**

Project title: Matrix for Chemical IT



Deliverable n. 3.3.1: Demonstrator, Restricted (RE) M12
“Amphiphile production linked to containers“

Temporary only for restricted circulation

Due date of deliverable: 31.01.2011

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Start date of project: **01.02.2010**

Duration: **3 years**

Organisation name of lead contractor for this deliverable: University of Southern Denmark, SDU

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This report covers the work undertaken to realize the deliverable 3.1. So far only the result on the vesicle systems have been published (Maurer et al. 2011 “Interactions between catalysts and amphiphile structures and their implications for a protocell model.” ChemPhysChem, 12, 828-835).

The general goal of the following investigations was to explore the possibility for amphiphile structures to support the photocatalytic production of amphiphiles from precursor molecules. The research focused on understanding how structures may alter photochemical processes by providing co-localization of all molecules involved in the production of amphiphiles.

Types of containers

Due to the various containers proposed in the MATCHIT project, the feasibility of the production of fatty acids (FA) by photofragmentation reaction was demonstrated in three self-assembled containers or on their surface: FA vesicles, oil-in-water droplets stabilized by a monolayer of FA (o/w droplets) and reverse-micelles of FA (RM) in an apolar phase composed of isooctane and 1-octanol (9:1). The physical properties of these three systems are quite different, but all present an interface between an oily or like-oil phase and an aqueous medium on which amphiphilic molecules or hydrophilic molecules derivatized with hydrophobic anchors, such as simple hydrocarbon tails, can accumulate durably.

To test the effects of the interfaces on the photocatalyzed fragmentation of the FA precursors several systems were envisioned and the corresponding molecules synthesized (Figure 1).

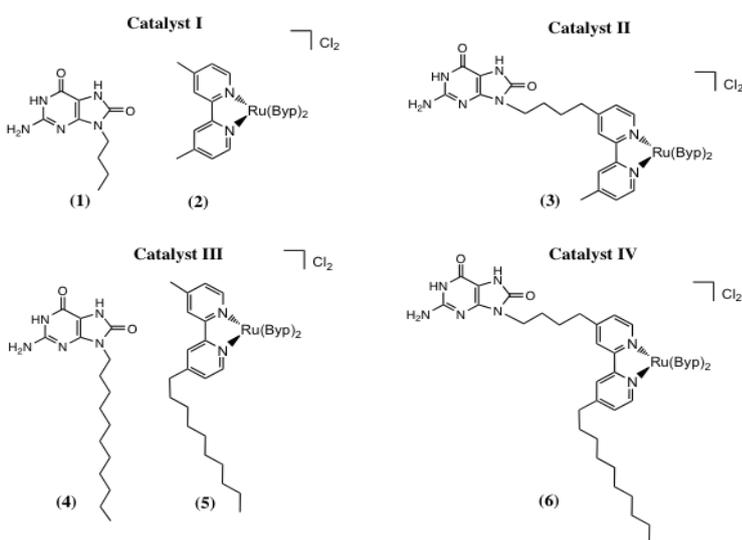


Figure 1: Catalyst configurations I to IV. **Catalyst I:** aqueous intermolecular catalyst, 9-butyl-8-oxoguanine [or 2-amino-9-butyl-1H-purine-6,8(7H,9H)-dione] (1) and [Ru(II)(bpy)₂(4,4'-dimethyl-bpy)] chloride = diMeRu (2); **Catalyst II:** aqueous intramolecular catalyst, bis-(2,2'-bipyridyl)-(9-N-[4-(4'-methyl-[2,2']bipyridinyl-5-yl)-butyl]-8-oxoguanine)-ruthenium chloride = 8-oxoGRu (3); **Catalyst III:** lipophilic intermolecular catalyst, 9-undecyl-8-oxoguanine (4) and [Ru(II)(bpy)₂(4-decyl,4'-methyl-bpy)] chloride = RuC10:0 (5); **Catalyst IV:** lipophilic intramolecular catalyst, bis-(2,2'-bipyridyl)-(9-N-[4-(4'-decyl-[2,2']bipyridinyl-5-yl)-butyl]-8-oxoguanine)ruthenium chloride = 8-oxoGRuC10:0 (6).

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Studies were carried out to investigate the interaction of the various ruthenium complexes with the various containers. diMeRu (Figure 1, molecule 2), which is highly soluble in aqueous media, was shown to electrostatically interact with the negatively charged interfaces. The associated fraction of ruthenium complex was dependent on the surface charge density of the FA containers.

New ligands were synthesized that possessed a hydrocarbon side chain ($C_{10}H_{21}$ or $C_{11}H_{23}$) attached to one of the bipyridine ligands (Figure 1-5). This derivatization resulted in a very extensive association (over 95%) of the ruthenium complex with the container interfaces which was independent of the surface charge density. Similar results were obtained for 8-oxoGRuC10:0 (Figure 1-6). Interestingly, 9-butyl-8-oxoguanine (Figure 1-1), did not associate with any interface, and remained in the aqueous volume, whereas its long hydrocarbon tail counterpart, 9-undecyl-8-oxoguanine (Figure 1-4) associated well.

Amphiphile production without containers

In the absence of any container, the precursor molecules form a separate phase in water. Due to sample preparation method, which extensively relies on sonication to remove oxygen, the precursor was present as small droplets. In these samples, the photofragmentation reaction rates were observed to increase according to the following sequence, Catalyst I < Catalyst III < Catalyst II < Catalyst IV with an approximate 1:20:45:90 rate ratio. The rates of the photochemical reactions were therefore dependent on both the catalyst-precursor association and the ruthenium-nucleobase covalent linkage. The picture obtained was clearly consistent with the general catalysis rules: intramolecular reactions are preferred to intermolecular reactions, as is the close proximity of the substrate to the catalyst (i.e., the non-covalent association of the catalyst with the precursor).

Amphiphile production supported by FA vesicles

The intermolecular reaction with Catalyst I was very slow in the presence of FA vesicles due to a poor association of the 9-butyl-8-oxoguanine with any oil-like or amphiphile structure. The inclusion of a covalent linkage of the ruthenium complex with the nucleobase resulted in a significant rate increase. In contrast, the rate difference between intra- and

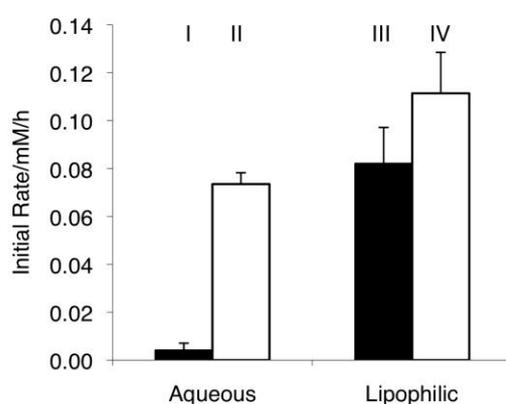


Figure 2: Rate dependence on catalyst configuration in the presence of preformed FA vesicles. The reaction mixture was composed of 0.1mM of Ru-catalyst, 5mM precursor, 10mM decanoic acid, and 15.75mM H-source at pH=7.0, which was adjusted using NaOH. The numbers above the bars correspond to the catalyst numbering in Figure 1.

intermolecular reactions (Catalyst IV versus III) for the lipophilic cases became almost

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insignificant (Figure 2 Catalyst IV vs III). The rates achieved in *intermolecular* lipophilic configuration (Catalyst III) were also comparable to those of *intramolecular* reactions where the catalyst interacted electrostatically with the bilayers (Figure 2 Catalyst III vs II). Thus, the reaction rate in these three reaction mixtures seemed to depend more on the interaction of the catalyst with the membrane than on the linkage between catalyst and nucleobase.

The presence of the bilayer structures also significantly reduced production rates. This influence can be explained by insertion of the precursor molecules into the preformed vesicle bilayers. The structures were effectively diluting the local concentration ratio of the catalyst to precursor, as well as increasing the distance over which the electron transfer (ruthenium complex to amphiphile precursor) occurred. One might also speculate that the decanoic acid in the bilayer restricted the movement of precursor, towards the catalyst. In any case, the precursor-catalyst interaction would be prevented to some extent.

This dilution hypothesis was investigated by increasing the concentration of decanoic acid-decanoate (0 to 30 mM) in the reaction mixtures. Increasing the concentration of decanoic acid from 0 to 5 mM in the starting reaction composition (5 mM precursor and 0.1 mM Catalyst IV) caused a clear decrease in initial conversion rates. At the end of this decanoic acid-decanoate concentration range, vesicles began to form and impact the the reaction rates confirming the previous general observation. Further increase in starting decanoic acid-decanoate content induced a steady rate decline that might be attributed to the dilution of system components due to the expanding bilayer structures. The efficiency of the catalysis depended on the ratio of catalyst to precursor for a given surface area. That is, an increase of surface area (due to the higher decanoic acid concentration in the sample) could be counteracted by increasing the concentration of catalyst and precursor by the same factor.

The presence of vesicles can alter the conversion rates expected by general rules of catalysis. The conversion rate became less dependent on the ruthenium complex-nucleobase catalyst configuration as long as both the ruthenium and the oxoguanine are associated with the bilayers. Indeed, at the relatively high local concentrations of catalysts resulting from the insertion in the interface, the advantage of the covalent linkage almost completely disappeared. This result indicated that the bilayer, i.e., the container, is sufficient for the co-location needed for efficient electron transfer between the nucleobase and ruthenium complex [Maurer et al. 2011].

Amphiphile production supported by FA o/w droplets

The slightly altered catalyst system was used here due to o/w droplets preparation method. The 8-oxoguanine was replaced by ascorbic acid, which can both give an electron and an H-atom to the ruthenium trisbipyridine. In such configuration, a stoichiometry excess of ascorbic acid to diMeRu is needed (2:1). The precursor molecules were dissolved in the oil carrier (nitrobenzene) and fatty acids added to the aqueous phase to stabilize the container. The photofragmentation of picolyesters was detected albeit at lower rates compared to a reaction where the precursors alone form transiently stable microemulsions.

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Amphiphile production supported by FA RMs

Stable RM systems were prepared using decanoate as the interface stabilizing molecules and an apolar phase composed of isooctane and 1-octanol (9:1), which is necessary to stabilize the interface as it reduces the repulsive interaction between the negatively charged decanoate molecules. The other compounds needed for the photochemical fragmentation reaction were either dissolved in the aqueous phase at high pH (Catalyst II, H-atom source) or in the apolar phase (FA precursor).

Within the range of stable w_o (18 to 72), the size of the resulting RM was measured to reach a maximum diameter of 30 nm. The conversion of the precursor did not occur according to the Figure 1 even with ruthenium trisbipyridine and ascorbic acid instead of the more complex Catalyst I. We surmised that the crowding of the aqueous solution that was likely to have occurred at the relatively high concentrations of chemicals used for the reaction, preventing a successful reaction process.

To solve the problem of crowding, the interface and possible interactions with it were explored successfully. The derivatization of ascorbic acid with hydrocarbon-chain anchors, which causes their insertion into the decanoate-coated interface between the apolar and aqueous phases, allowed for the detection of the correct photofragmentation product.

Summary of the results for D3.1 “Implementation of amphiphile production linked to containers (M12)

We have been able to demonstrate a photofragmentation reaction catalyzed by ruthenium complexes that converts their picolyester precursor into FAs in good yields. Furthermore, we have shown the interactions between three different containers and the catalytic system (i.e., the insertion of some of system components into their interfaces) are essential in shaping the reaction outcome and can result in alteration of the chemistry.

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