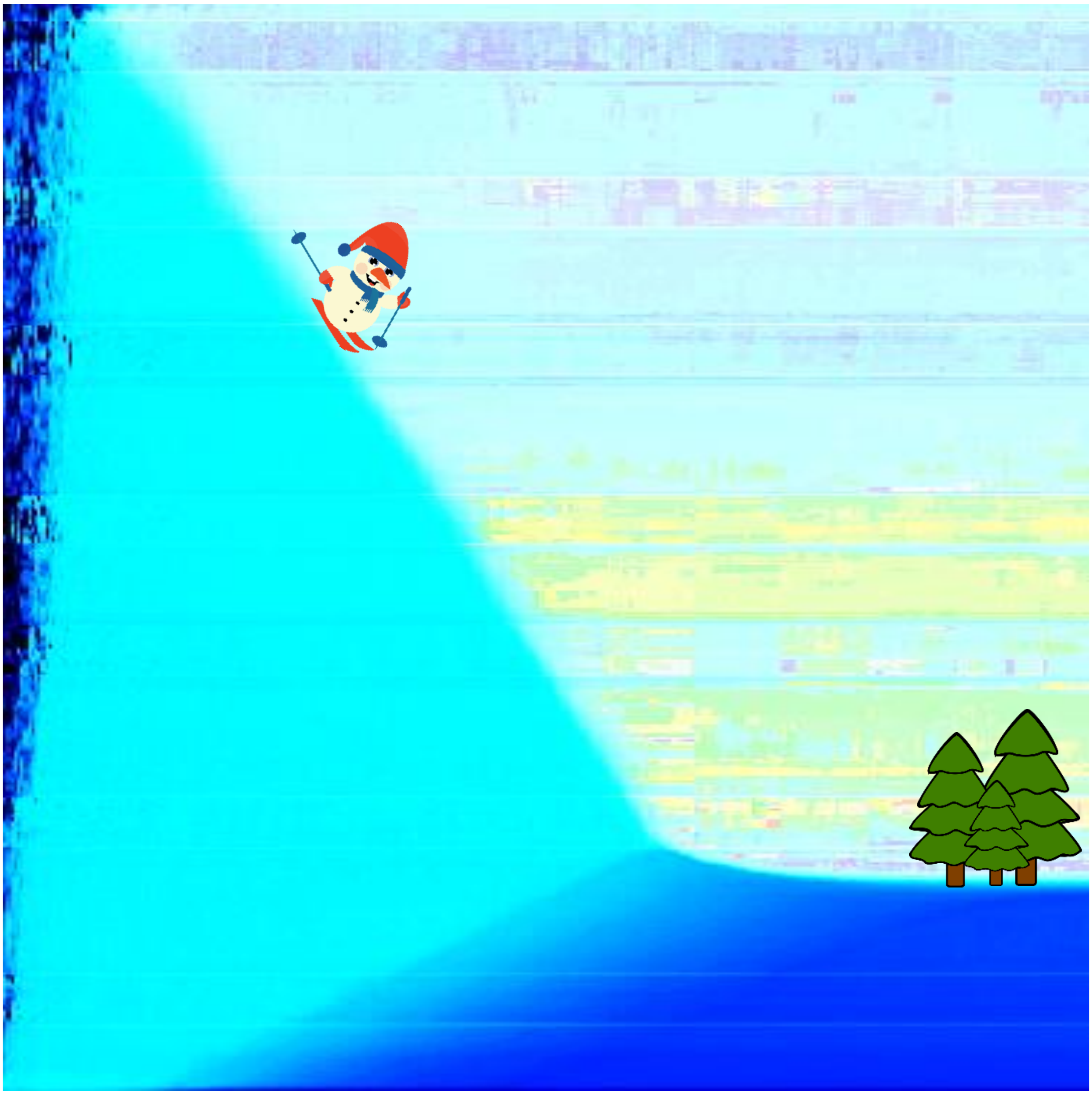
Separation and Purification



2018

Content

title photo by:
David Leleu, showing a first result of an automatically evaluated experiment with the iso-optical system in the settling cell

Dear Reader

Another year has passed too quickly. It has been a year full of change and challenges.

At the beginning of the year Maria Chiara Quaresima left the group. For her south-Italian soul the weather was too bad in Belgium, keeping in mind that Liège lying close to Aachen of course has the same well-known abundant rainfall, and that the last months of 2017 were the darkest since decades as documented in meteorological statistics. Her teaching-assistant duties were then taken over by Junior Franck Ekorong Akouan Anta, or Junior Ekorong for short. He continues the work on extraction with highly viscous phases.

Then, again Mr. Khang Vu Dinh from the University of Industry in Ho Chi Minh City in Vietnam visited for several months. His work is closely related to that of Zaheer Shariff, both working on phosphorous recovery from sewage sludge. One goal was to more closely combine their work in order to unleash synergies. Also Mr. Khang managed the formalities to become Ph.D. student of the University of Liège.

Also this year teaching visits to Bangkok and Oman were organized. With all preparations and travelling times this contributed roughly 10% of the annual working time. Nevertheless, it is always rewarding, realizing that one succeeded in passing on some of the own experience.

Meanwhile some of the former regular events have been re-established, some already end of last year, namely the preparation of cookies for the Christmas lecture. Some of the cookies of course remain as desert for the official department Christmas lunch. Also we went on a group outing, surrounding a lake on a nice late summer day.

Finally, also personally big milestones have been reached, finishing a book on our successful future. Not an easy read (what else would you have expected?), so not explicitly recommended. It summarizes a philosophical perspective, which clarifies, why we are individually responsible. Then the question is answered, which responsibilities we actually have, if humanity shall reach sustainable well-being for everybody. The perspectives are actually rather horrifying, especially when realizing towards the end of the year that major assumptions in the scenarios developed to guide politics can be shown to be clearly wrong. This topic has been worked out meanwhile to a certain detail. It is e.g. shown in which context bio-economy can work in a sustainable environment, which has been presented partly at the ProcessNet Jahrestagung in Aachen. Corresponding videos have then been prepared and supplied via YouTube.

Concerning research, progress is visible but always too slow (citing one of my teachers, John Prausnitz). A major breakthrough has been achieved in describing coalescence by David Leleu, finally being able to put all known details of coalescence of drops properly together to formulate a consistent model. Then Zaheer Shariff together with Laurent Fraikin from the group of Angélique Léonard established all process steps for phosphorous recovery on lab scale and succeeded in modelling with e.g. proper thermodynamics all relevant process steps. Junior Ekorong finally managed to acquaint himself with the topic of extraction and established essentially the state that was achieved when Maria Chiara Quaresima left. Thus, everything is well on its way, as you can again realize when browsing through this brochure.

So: Enjoy reading!

Andreas Pfennig

ReDrop to Simulate the Settling of Liquid-Liquid Dispersion

David Leleu

Continuous and batch settlers are used in processes in order to separate liquid-liquid dispersion. Their design can be challenging, e.g. quantitatively predicting the remaining fraction of fine drops found at settler outlet as function of the operating conditions. For the batch-settler design, a numerical tool has been developed, which is based on the ReDrop concept (Ayesterán et al. 2015). This tool, which applies a Monte-Carlo method to solve the drop population balances, allows to simulate the separation of liquid-liquid dispersions and thus to optimize the design of continuous settlers. Sedimentation and coalescence are evaluated for a sufficiently large ensemble of representative individual drops at each time step. The time needed for the settling process is determined from the simulation. The information can be used to design a settler. In these simulations, the coalescence modeling is a major challenge due to the complex interactions of drops upon approach and during the coalescence process.

ReDrop concept

The ReDrop approach considers each individual drop present in the system. Their individual velocity is evaluated at each time step with a suitable sedimentation model in order to follow their individual vertical position in the settling cell. The coalescence probability is then evaluated for drop-drop coalescence in the sedimentation and dense-packed zone and for drop-interface coalescence with the major interface. The horizontal position of the drops is not accounted for. Thus, only the probability that two drops meet can be evaluated in order to quantify correctly the probability of a coalescence event, which is then realized with a Monte-Carlo approach in the simulation.

For the simulation, the settler height is subdivided into height elements which allows the evaluation of the local hold up. The latter influences the sedimentation velocity and is taken into account in the modelling. The local hold-up calculation is used also to obtain a visual representation of the settling as presented in Fig. 1.

The coalescence model

As shown in Fig. 2, the probability that two drops coalesce depends on three variables. The first is the frequency with which they meet, defined by the so-called collision rate. The second parameter is the bouncing probability, which characterizes the probability that the drops stay in contact after the collision. If they do not, the collision leads to the direct bouncing without any chance to coalesce. The final variable influencing the coalescence probability is the efficiency with which they coalesce once they met. The coalescence efficiency in turn depends on the time, during which the drops stay in contact and the time they would need to coalesce.

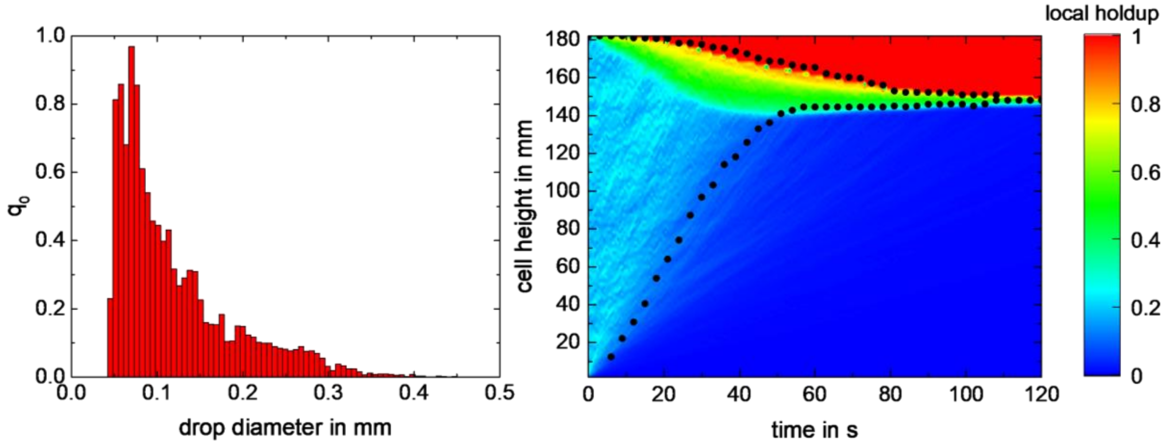


Fig. 1: Simulation of settling experiment with the ReDrop tool

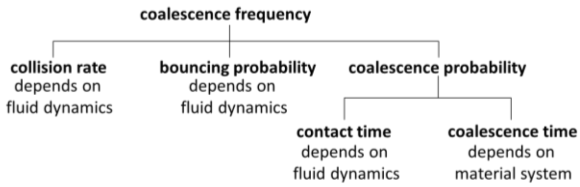


Fig. 2: Coalescence model

It turns out that solely the fluid dynamics of the regarded equipment determines the frequency with which drops meet, the bouncing probability and the time they stay in contact. The differences in equipment to which this model is applied characterize the fluid dynamics, which thus has to be characterized only once for a given type of equipment. The time the drops need to coalesce on the other hand only depends on the specific material system used (Kopriwa, Pfennig, 2016).

Coalescence probability

The developed model expresses the coalescence probability by:

$$p_{\text{coalescence}} = 1 - \exp\left(-\frac{t_{\text{contact}}}{t_{\text{coalescence}}}\right)$$

whereas the widely used model of Coulaloglou and Tavlarides is expressed by:

$$p_{\text{coalescence}} = \exp\left(-\frac{t_{\text{coalescence}}}{t_{\text{contact}}}\right)$$

The developed equation describing the coalescence probability is thus fundamentally different from the model of Coulaloglou and Tavlarides, which is inconsistent at a basic level. Indeed, their model cannot expresses similar coalescence probability if the time step is varied.

Model validation

The coalescence time can be evaluated experimentally from any suitable settling experiment. Here the experiments are conducted in the standardized settling cell. The equipment was developed in the framework of the ERICAA project. The cell proposed by Henschke (Henschke et al., 2002) was optimized and validated. It consists of a glass vessel with a capacity of 800ml, with 2 shafts for stirring with 4 stirrers on each shaft. An endoscopic probe (SOPAT-VR-Sc) is used to measure the drop-size distribution in situ. ATEX regulation has been also taken into account in order to work with volatile solvents.

In order to validate the coalescence model and the numerical approach, a measurement of the local holdup at any height of the cell and at any time is necessary to be compared to the simulation. Here, iso-optical systems are used, because the interface is invisible in such systems, in contrast to usual system with different refractive indexes of the phases. In addition, a dye is added to one phase, so that color intensity then allows the direct determination of the local holdup as function of height and time (see title photo of this brochure).

First results are depicted in Figure 1. It shows on the right side a simulation performed with the ReDrop program. The model parameters were fitted in order to follow the experimental data shown by the black dots. The initial drop-size distribution used in the simulation was measured with the SOPAT probe and is represented on the left side of the figure. This is a good starting point for the model validation and the use of iso-optical system will complete the validation.

Acknowledgements

This work was supported by the FNRS and by the Federal Ministry for Economic Affairs and Energy of Germany through the ERICAA project.

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Single-Drop Sedimentation Velocity for Highly Viscous Systems

Junior Ekorong

Motivation

Solvent extraction is used e.g. in pharmaceutical and biotechnological engineering. During the operation, a liquid extractant is added to a process stream to remove one or more components from that stream. In previous work, a design method has been developed, which utilizes models describing the behaviour of individual drops of the dispersed phase in an extraction column (Altunok *et al*., 2006). It accounts for a limited number of elementary processes, namely mass transfer, sedimentation, coalescence and splitting, including the so-called swarm effects. The effect of column internals is also take in account. The drop-models applied contain material-specific parameters that are fitted to results of experiments with individual drops in dedicated lab-scale experiments.

Sedimentation, like the other elementary processes, has been intensively studied. For low-viscous systems, many models describing the sedimentation behaviour of drops are available. In the past some studies have been performed, which allow first ideas on how systems with increased viscosity may behave. Especially, Adinata (2011) performed an orienting study on viscous systems. One of the results is that the parameter α_{sw}, which describes the sharpness of the transition between rigid drops and drops with internal circulation in the Henschke model for drop sedimentation (Henschke, 2003), has to be adjusted. For low-viscous systems, Henschke kept it constant. Therefore, the viscosity influence on the sedimentation model needs to be investigated more systematically.

The Method

The sedimentation velocity of drops rising in a continuous phase will be investigated. As in the studies of Adinata (2011), in one of the systems proposed by the EFCE, the viscosity of the aqueous phase will be increased by adding PEG (polyethylene glycol), and paraffin oil will be added to the organic phase. The sedimentation velocity is then determined in a single-drop cell shown in Fig. 1.

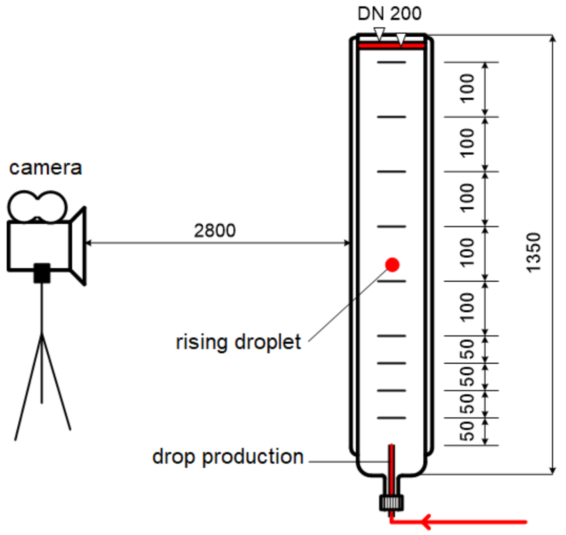

Fig. 1: Sedimentation cell for the measurement of single-drop terminal velocity

The cell consists of a cylindrical vessel with temperature control. Inside this vessel, a drop of known volume is produced with the help of a computer driven syringe, which can inject a defined volume of dispersed phase at a defined velocity via a glass nozzle. By finding the right amount of dispersed phase to inject and the right velocity to correctly produce one single drop, individual drops with identical drop diameter can be generated. Each drop detaches from the glass-nozzle tip and its path is then recorded with a high-resolution video camera. From the recorded videos, the time needed by the drop to rise in the continuous phase through a defined distance is determined, characterizing its sedimentation velocity. Then, the model parameters are fitted to experimental data.

Preliminary Results

As the drop diameter increases, the sedimentation velocity will reach a maximum, and then decreases again. A comparison between the models used for describing low-viscous systems shows that only the models from Vignes, Henschke and Grace *et al*. in Fig. 2 allow to describe this behaviour.

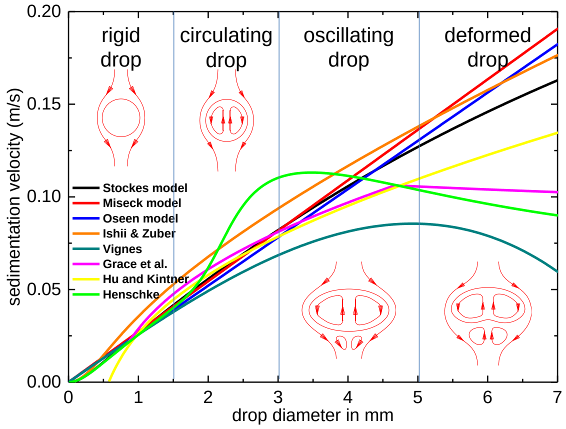

Fig. 2: Models for sedimentation velocity as a function of drop size (system: butyl acetate + water)

Among the models found in the literature, only the Henschke model takes into account viscosities of both phase. A sensitivity study, carried out by varying each phase viscosity, allow observing two different behaviours, depending on the properties of the phases involved. As shown in Fig. 3, increasing the dispersed-phase viscosity may lead to a reduction of the drop viscosity up to around 25 mPas, with no significant change by a further increase.

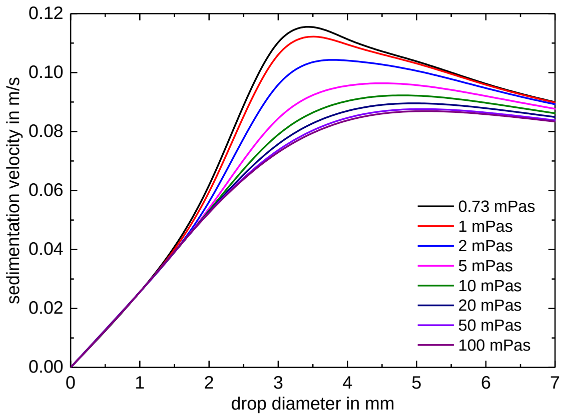

Fig. 3: Effect of dispersed-phase viscosity on sedimentation velocity (system: butyl acetate + water)

On the other hand, Fig. 4 shows an expected continuous decrease of the velocity as the continuous phase viscosity increases. This decrease remains large also at high viscosities.

The decrease of sedimentation velocity predicted by the model agrees with Adinata's (2011) observations. This sensitivity study allowed the identification of drop diameters and viscosities, at which the experiments are best performed to discriminate between the models.

Based on these preliminary studies, a more systematic approach towards varying phase viscosities will be taken. Also the variation of viscosity of both phases simultaneously will be investigated. The obtained results allow establishing a clear relation between the variation of viscosity of one or both phases and drop sedimentation. Models do not take directly in account the transfer component concentration, even if its presence has an effect of the physical properties of the phase that contains it. Therefore, in a following step experiments will be performed to depict the effect of the transfer-component concentration on the sedimentation velocity in highly viscous systems.

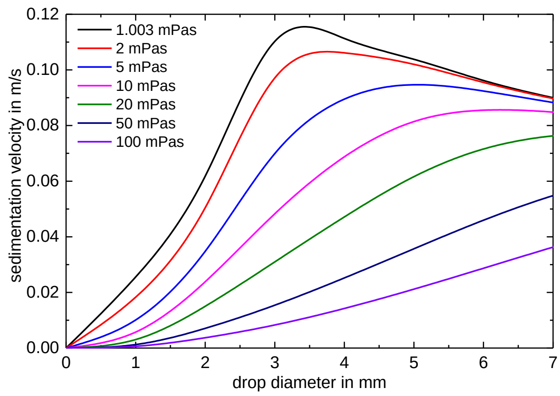

Fig. 4: Effect of the continuous-phase viscosity on the sedimentation velocity (system: butyl acetate + water)

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Modelling of Solid-Liquid Equilibrium and its Application for Optimization of the PULSE Process

Zaheer Shariff

Phos4You project and PULSE process

Phosphorous (P) is an essential element for life and has a limited availability in nature. Mineral P is mainly produced from phosphate rock. In the EU more than 90% of P used is imported to meet its requirements. As a result, significant research has been directed towards finding economical ways of recycling P from waste streams, which otherwise will be lost to landfills or the oceans. A new P-recovery technology called Phosphorus ULiège Sludge Extraction (PULSE) process as shown schematically in Fig. 1 is being developed at ULiège. It is aimed at recovering P from partially or fully dried sludge from wastewater treatment plants followed by extraction of heavy metals and/or P to obtain a high quality P-product that can be used for fertilizer production. This research is part of the PhosForYou (P4Y) project. In the first phase, experiments are being conducted at lab scale to optimize the individual unit operations. The method of cascaded option trees is used for designing and improving the process, which allows systematic bookkeeping of the various options available and keeping track of the feasibility test with respect to the critical criteria.

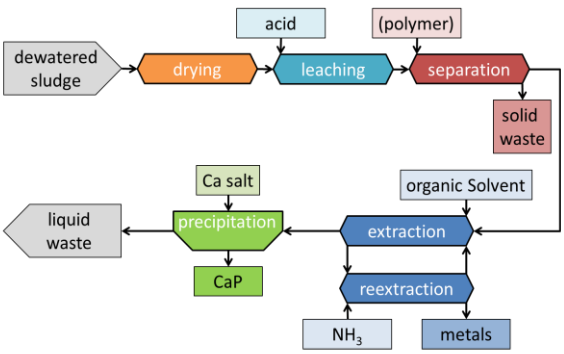

Fig. 1: Simplified process flowsheet of PULSE process

In the second phase, the process will be demonstrated with a pilot plant. The pilot plant is designed to have a capacity of treating 100kg of dewatered sludge per day and will be tested at four wastewater treatment plants in Belgium, Germany, Ireland, and Scotland.

Solid-liquid equilibrium (SLE) modelling

As the composition of wastewater and thus of sludge varies from one location to another and also from season to season, the operating conditions of the PULSE demonstrator will have to be optimized for individual situations. In the PULSE process, the most important operational parameter for the unit operations leaching, reactive extraction, and precipitation is the pH. The pH controls the types of ions or complexes that exist in a solution and the species that will precipitate at equilibrium, knowledge of which is critical to optimize the PULSE process operation. Therefore, a model was developed in MATLAB in order to simulate the SLE based on the solution pH as shown in Fig. 2. The activities of aqueous ions or complexes in a solution are governed by the laws of mass action (LMA), the mass balances (MB) and the charge balance (CB). A non-ideal solution due the interaction between ions is assumed. The most common activity-coefficient model is the Debye-Hückel model and its variations which are mostly dependent on the ionic strength of the solution. In the current SLE model, two variations of DH model i.e. the Davies and Truesdell-Jones model are implemented. These models can be used to calculate ion activity in solutions with ionic strengths up to 1 mol/L.

The activities of ions or species in solution is determined by solving the non-linear system of equations of LMA, MB and CB. The MATLAB inbuilt function ‘fsolve’ is used to solve these equations. Like most of the second order numerical iterative methods, fsolve requires a good initial guess (IG). The IG in the model is generated by a first order iterative method called the ‘positive continuous fraction (PCF)’ (Carrayrou , Mosé , & Behra, 2002). A modification is made to this method, then referred to as MPCF. For calculation of the IG, ideal solution is assumed. After the IG has been obtained, the model proceeds to calculate the ionic strength and activity coefficients of the ions in the system. These are then used to iteratively find the equilibrium activities and hence concentrations of the aqueous ions.

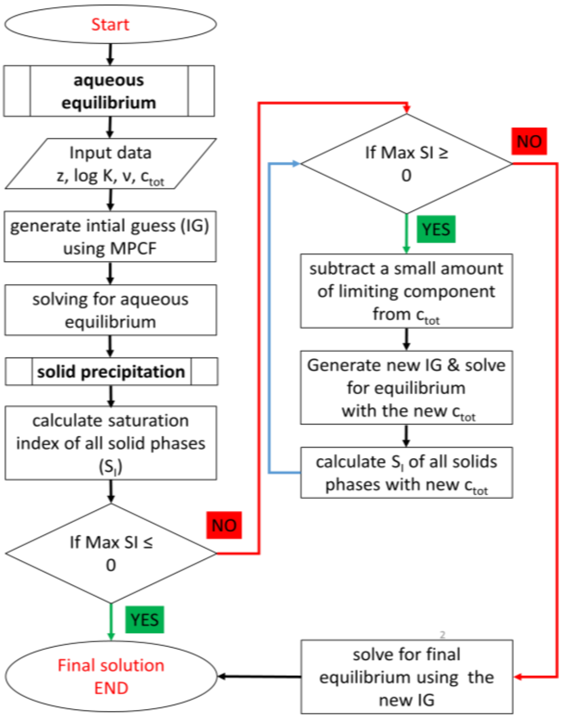

Fig. 2: Flowchart for the MATLAB aqueous speciation model

Once the activities of the aqueous ions have been determined, the next step is to check, if any solids are precipitating. Precipitation of a species depends on super-saturation of the solution, which is governed by the saturations index (S_I).

$$S_I = log\frac{IAP}{K_{sp}}$$

Here, IAP is the free ion activity product and K_{sp} is the solubility product of the precipitating species. It is known that the thermodynamic driving force for a chemical process is the change of Gibbs free energy ΔG, which for precipitation becomes

$$\Delta G = -\frac{RT}{n} ln\frac{IAP}{K_{sp}}$$

Here R is the ideal gas constant, T is the absolute temperature, and n is the number of ions in the precipitated species. The S_I then characterizes the situation with respect to the solid-liquid equilibrium as indicated in Tab. 1.

In the next step, the code iteratively calculates the IG for the precipitated solid which has the highest S_I. This is achieved by subtracting small amounts of the limiting component, mimicking its removal by precipitation of that component, until the S_I = 0. The same procedure is repeated until the S_I of all the potential solids considered are zero. Finally, the ultimate SLE is determined based on the generated IGs for the aqueous as well as the solid species.

$S_I = 0;\ \Delta G = 0$	solution is in equilibrium
$S_I < 0;\ \Delta G > 0$	solution is homogeneous, no precipitation possible
$S_I > 0;\ \Delta G < 0$	solution is supersaturated, precipitation occurs

Tab. 1: The solubility index characterizes the precipitation equilibrium

An example of the SLE simulation carried out using the developed MATLAB code for the simple system of aluminum-iron-HCl is shown in Fig. 3. A total of 19 aqueous species and two solid precipitates were considered in this example, but only the major species are shown for clarity. The information from this simulation can be used for optimization of leaching, extraction, and precipitation steps. The current model will further be developed integrate the individual unit operations into a single process in Simulink.

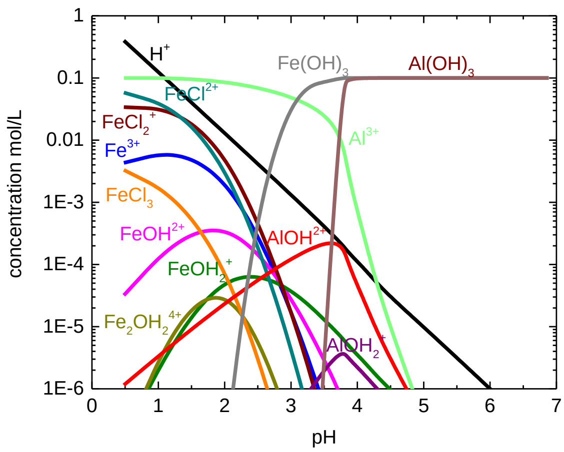

Fig. 3: SLE of Al^{3+}-Fe^{3+}-HCl as a function of pH, total c: Fe = .1 mol/L, Al = .1 mol/L, HCl = 1 mol/L to 10^{-06} mol/L

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Potential for Phosphorus Recovery in Southern Vietnam

Khang Vu Dinh

Introduction to potential sources of waste for phosphorus recovery

Southern Vietnam consists of two main areas: Southeast and Mekong Delta. This is where both industrial and agricultural production develop with Ho Chi Minh City being the most populous city with a population of nearly 8.5 million people in 2017. Potential sources for the recovery of phosphorus include: aquaculture, livestock, poultry farming, rubber processing, and centralized domestic wastewater treatment plant.

According to the General Statistics Office of Viet Nam, the southern region has more than 6.75 million pigs (2017). According to Vu Dinh Ton (2010), the estimated feed consumed during a fattened pig's life was about 258kg during the roughly 105 days of breeding. The amount of manure produced was 127kg. According to Sanchez and Gonzalez (2005), total phosphorus composition in pig slurry is 0.82 g/kg. Thus total phosphorus reserves in the pig manure was 700.000 kg in 2017.

Fig. 1: Getting sediment from catfish pond in Mekong Delta, Vietnam

After the preliminary research in Ho Chi Minh City, the total phosphorus content in sludge discharged from the Binh Hung domestic wastewater treatment plant, which has a capacity of 140000m^3/day, was 1.53% by weight. The organic content of the sludge is quite high, at 19.9%. Phosphorus content in this plant can be recovered maximum 600kg/day.

Similarly, the potential for phosphorus reserves from other sources will be assessed in detail over time.

Criteria for building process solutions

In order to be able to formulate a P recovery solution suitable to Vietnam conditions, the cascaded option tree has been established. There are similarities in the criteria that need to be met in the cascaded option trees for implementing P-recovery technology in Vietnam and internationally (see also Fig. 2):

- the efficiency of P recovery
- the cost of investment.
- the cost of operation.

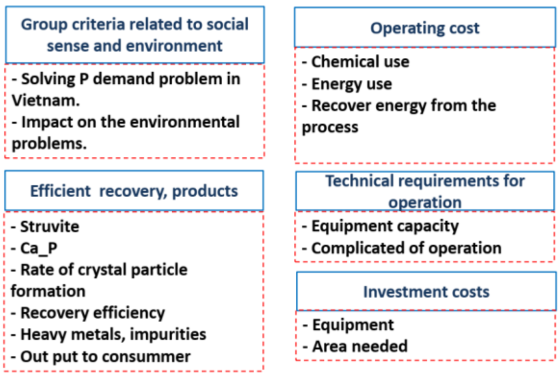

Fig. 2: Phosphorus recovery criteria which related to Vietnam conditions

Especially the low operating costs are an important consideration in Vietnam. There are many options for phosphorus recovery solutions. However, reducing operating costs and realizing an environmentally friendly process are very necessary and meaningful goals.

Shaping the phosphorus recovery process

There are many solutions to phosphorus recovery from solid or liquid raw materials. However, the solution in line with the criteria and conditions of Vietnam shall be the focus here. The phosphorus recovery process is gradually being established and continued updating. This process is designed not only to achieve phosphorus recovery but also to achieve the goal of using raw materials from nature. However, the assessment of recovery efficiency and in particular the feasibility of operating costs need to be carefully studied.

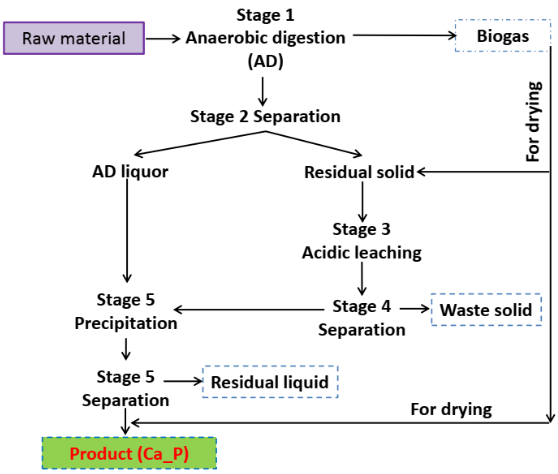

Fig. 3: Proposed process for phosphorus recovery

The process studied has the main goal of phosphorus recovery. Moreover, an environmental friendly process is desired. This can be realized by anaerobically degrading the high content of organic matter residues prior to the recovery steps. The produced biogas can then be used to generate heat energy for the sludge drying before subsequent recovery steps. Also, raw materials with natural origin as auxiliary components for P recovery process are tested such as snail shells and limestone – which are abundant raw materials in Vietnam.

Work plan 2019

In 2019, a review of the potential for phosphorus recovery in South Vietnam will be completed, which is the basis for assessing the suitability of technology solutions related to actual conditions in Vietnam.

With the objective of objectivity and accuracy, MATLAB software and other simple computational approaches are useful, especially for experiments involving chemical and biological reactions. The first step is to investigate the potential sources of raw materials used for the recovery of phosphorus. They include a survey of the raw materials rich in phosphorus and the source of the material that promotes the recovery process. Moreover, research steps that identify optimal conditions in anaerobic biodegradation and recovery will continue to be cautiously conducted in 2019. Sample analysis throughout the course of the experiment will be performed by a variety of methods. The use of ICP-OES chromatography analyzer provides great convenience and reliability as a basis for process optimization.

Fig. 4: Training course to ICP-OES operating by laboratory in Industrial University, Vietnam

Acknowledgements

This work was carried out both in Vietnam and Belgium. I am very grateful for the help and support of the laboratory of Chemical engineering at ULiège and the industrial University in Vietnam. I am very happy to work in the same field with Zaheer.

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Politics Misled by Unrealistic Population Scenarios

Andreas Pfennig

Since every single person has certain demands and requirements for food, materials, and energy, world population scales directly the total demands that need to be fulfilled on global scale. One major source for projection of world population, used by many studies, are the UN World Population Prospects (2018) (WPP). These data have also been used for own work on setting up and solving global balances more than 10 years ago. The current version of that projection is shown in Fig. 1 with its three variants. The medium variant is indicated as having the highest probability to occur, while the probabilities of the two other variants are essentially negligible, i.e. it is not to be expected that they might occur.

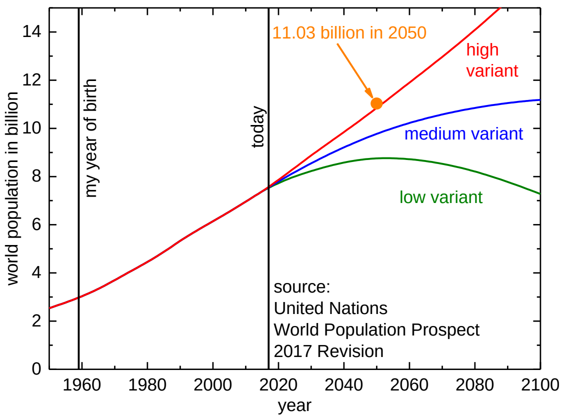

Fig. 1: The three variants of the UN World Population Prospects (2018)

What was intriguing is the fact that apparently the behavior had changed during the last decade. Since this is such a key parameter, its behavior was investigated a little more closely, as shown in Fig. 2, where the projections have been collected all referring to the year 2050, but published in different years, since the UN publishes updates roughly every two years. It is apparent that there is a clear trend in the data, especially of the low and medium variant, which – as an engineer – was approximated by a straight line. Since the world population of 2050 predicted in the year 2050 is not a projection but at most an estimation of the real value, it can be assumed that the three lines have to meet in a single point at that year. The slopes of the lines as well as that intersection point were fitted to the data since 2000. The resulting intersection point is included in Fig. 1 as well, showing that – if the trend in the UN projections persists – world population may even develop above the high variant.

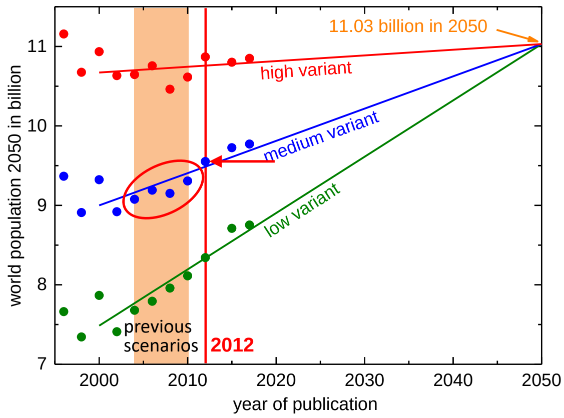

Fig. 2: Variation of the WPP over time

Such behavior would of course significantly and continually increase the pressure on all resources, since that means that world population may continue to increase exponentially during any foreseeable time. Of course there are reasons, why the UN projections are continually adjusted in upward direction:

- in sub-Saharan Africa fertility did not decrease as expected,
- child survival rate increased worldwide,
- and the effect of HIV was less than originally expected.

That these effects were not expected in previous projections is of course not a fault but simply the result of the future being 'open'. Future can very fundamentally not be predicted. Thus only possible futures can be described, as is usually realized via scenarios. Formally, this can be distinguished as

- uncertainty, which characterizes known possible inaccuracies, the magnitude of which can typically at least be estimated,
- and ignorance, as technical term meaning the unavoidable lack of knowledge, which fundamentally cannot be quantified.

Thus, since it cannot be excluded that our increasing knowledge will proceed as in the past, the high variant of world-population projections has to be regarded as a realistic option, with all the detrimental consequences.

In preparing a publication, literature was studied on how the projections are used and discussed. At that point, it became obvious that the variation over time had not been accounted for and even misinterpreted. This can best be understood, if the population projection of the IPCC (Intergovernmental Panel on Climate Change, Weltklimarat) from the fifth assessment report is regarded as shown in Fig. 3. Since the IPCC (2014) states that “the scenarios were generated by experts making informed judgements about how key forces might evolve in the future...”, one may reach the conclusion that experts draw a quite homogeneous picture, since the 90%-range of the evaluated scenarios is rather narrow. Also, they agree that world population develops clearly below the medium variant.

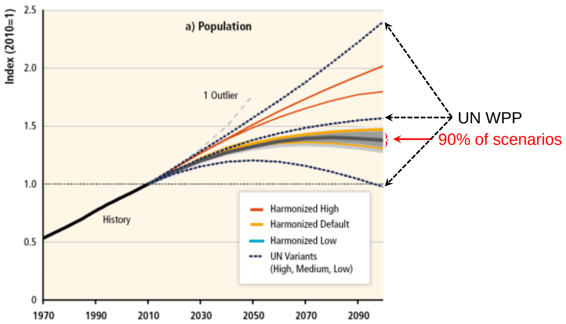

Fig. 3: Population projections regarded by the IPCC (2014), the arrows and text to the right have been added to clarify

How wrong this conclusion is, becomes obvious, if Fig. 2 is regarded. The UN-scenarios shown in Fig. 3 are those of the year 2012. The scenarios evaluated to yield the 90%-range as indicated in Fig. 3 have been using the scenarios between 2004 and 2010, always in the medium variant. From Fig. 2 it becomes obvious that the 90%-range is so narrow, because UN only slightly shifted the projections between publications. That this range lies below the medium variant is on the other hand solely result of using a later WPP for comparison, which had shifted upward even further.

The consequences can be seen, if the most recent IPCC report is regarded as shown in Fig. 4. Here the current so-called illustrative model pathways are shown in blue, which are used to derive the scenarios as basis e.g. for the climate conference in Katowice. Also in this most recent publication, basis of the IPCC special report on 1.5°C climate change published in October 2018, these P1 to P4 scenarios lie again below the medium variant. This is highly relevant even for the sustainable energy transition, because for most scenarios reaching the 1.5°C climate goal significant amounts of bio-energy are regularly included. If population develops only according to the medium variant, there will not be sufficient land area available even to feed all people, let alone, if the high variant should occur. Thus, the proposed energy scenarios cannot be reached and the corresponding basis for policy development unfortunately is simply wrong with all fatal resulting consequences.

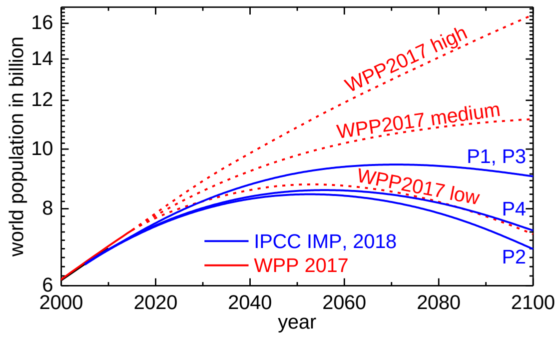

Fig. 4: Comparison of blue illustrative model pathways (Huppmann, 2018) to WPP

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Systems View of Sustainable Economy

Andreas Pfennig

For processes in the Chemical Industry as well as for liquid fuels, two sustainable feedstock options exist, which would be feasible in a decarbonized economy:

- bio-based feedstock
- CO_2 from point sources or/and the air

Today, bio-based processes are already available on larger scale. Utilizing CO_2 on the other hand would have the advantage that no agricultural land area is required.

Agricultural land area is a scarce resource. The feedstock not only for bio-based materials but also bio-fuels and sufficient food for mankind need to be produced. In some of the Illustrative Model Pathways of the Intergovernmental Panel on Climate Change (IPCC) (Huppmann, 2018) as well as in the scenarios used as basis to derive the European Sustainability Strategy, a significant increase in bio-energy is considered for fulfilling the increasing energy demand of growing world population. This induces significant additional pressure on fertile land area. Thus population growth, sustainable energy transition, bio-economy, and sufficient food supply are strongly interlinked challenges. The intensity of this interaction becomes clear, if it is recalled that compared to 1990, the reference year for many UN goals, we are today feeding 2.5 billion more people. Unfortunately world population has increased during that time by 2.3 billion, resulting in a reduction of undernourished people only by 200 million people. Thus today still more than 800 million people are undernourished.

To visualize the interplay in this system of interactions, a variety of balances has been applied and solved. A central balance is that shown in Fig. 1 for the high population variant (see previous contribution in this brochure). The land-area requirement has been characterized assuming a continual linear increase in land-area specific agricultural productivity and a continual intensification of animal-based food production. The white line characterizes, how agricultural land area changes only due to population growth. Overall it is obvious that the land area available per capita is quickly decreasing, if world population is developing according to the high variant. As a consequence, around 2050 we need to either further cut down forests to feed the people, or develop agricultural productivity significantly beyond the assumed maximum growth rate, which is unlikely to occur, or more people will remain undernourished. If population growth would follow the medium projection of the UN, until 2060 the land area will still be used at its limits, and only after that some area will become additionally available. Finally, if we would shift to solely plant-based nutrition, the land area for pasture and half that for feed would be freed instantaneously for other purposes. The other half of the land for feed production would be required to produce the plant-based food replacing the fraction of animal-based nutrition.

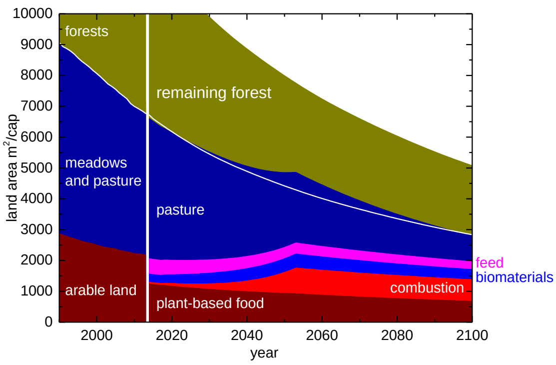

Fig. 1: Land-area utilization for the high population variant

Thus, it becomes obvious that behavior about number of children and nutritional habits, i.e. ethics, is more important than technical aspects, since not changing behavior will always force technology to develop at utmost rate. It is also foreseeably that in the future this may become difficult, especially, if climate change will negatively influence agriculture. Increase in bio-energy as assumed in many scenarios will increase world hunger directly as well.

It has then been evaluated, which option for a bio-based economy exist, as shown in Fig. 2. Here the land areas required to individually supply all feedstock for the Chemical Industry is described with typical land-area specific productivities. The entire range of land area shown is the agricultural land area in 2050 for the high population variant. It becomes clear that there exist a variety of options, where the green bars indicate those where the first steps are already today realized on technical scale. It also can be seen that solely third-generation biomass will not allow to supply sufficient feedstock, so that competition with food production can only be minimized but not avoided.

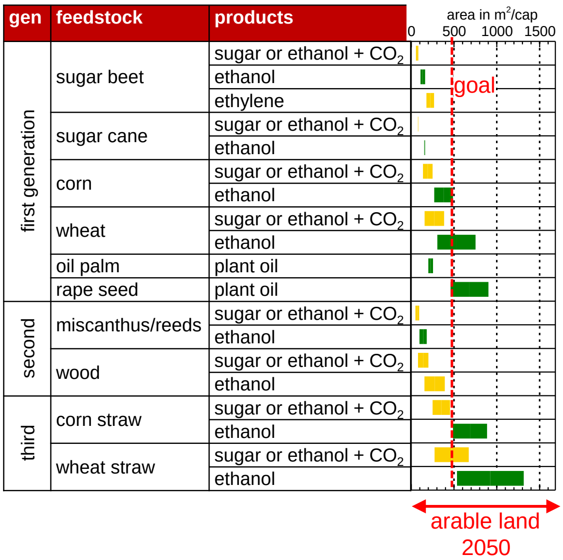

Fig. 2: Options for a bio-based chemistry

Another key graphics is shown in Fig. 3, which shows the effort to reach the climate goals, if we only start to foster sustainable energy transition somewhat later. This is shown for two climate goals. The effort is characterized by the substitution rate, which specifies, which fraction of primary-energy consumption is substituted by renewable energies in one respective year. Obviously for reaching the 1.5°C climate goal we have already reached the steep part of the curve, meaning that every year we wait to finally significantly increase or effort starting out at a current substitution rate of roughly 0.5%/a, the required effort for reaching the climate goal will significantly increase.

Comparing this globally required effort with the current status of how climate goals are tackled, it appears factually unrealistic that humanity is able to limit the climate change to +1.5 °C above pre-industrial level. Politicians have missed to realize that the system has shifted from the deceptive flat part of the curve into the steep section, where any further delay renders the goal increasingly unattainable. At the same time it is obvious, why reaching this conclusion is so difficult. It is apparently still possible to reach that climate goal, but the effort is quickly increasing significantly according to the essentially hyperbolic function, where beyond a certain point the required effort can in principle be reached but becomes practically unreachable. That economically reachable limit may lie somewhere around 3%/a substitution rate.

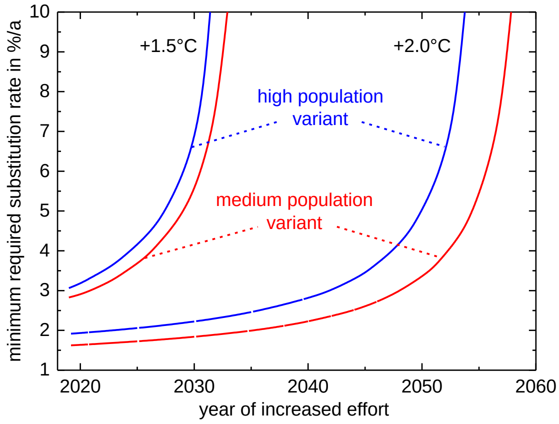

Fig. 3: Substitution rate that is required to reach climate goals, if we start to foster sustainable energy transition only later

With such simple balances it is thus possible to clearly visualize the major interdependencies in this global system. Only, if all these aspects – and some more – are properly accounted for and managed, humanity will be able to survive in wellbeing for everybody. To describe these interdependencies, a video series has been recorded for YouTube, which can be accessed via www.chemeng.uliege.be/successfulfuture, and a book has been written (Pfennig, 2018), which, as already indicated on the first page of this brochure, is not an easy read, because it also works out some fundamental ideas on a corresponding ethical foundations.

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My time in Liège, 2018

Khang Vu Dinh

Autumn in Europe

This is the second time I have come to live in Liège for a longer time. This time, I came when the weather was going to fall. Liège had a quieter and more peaceful space than my hometown – Ho Chi Minh city, the busy city. Liège welcomed me with a light rain in the late afternoon. My homesickness immediately seemed to fill my mind.

Fortunately, it was just a moment. I realized that there are so many interesting things of this city I have to explore. The scenery, culture, and people of Europe are fascinating things to me when thinking of Liège. The rows of trees, leaves are turning color as saying that they are ready to receive a cold winter. Autumn in Europe is beautiful, strong, and romantic.

ULiège and friendly people here

I was fortunate to study and do research at ULiège. Learning in the space covered by the forest gives me a feeling of freshness to each breath

2018 is very important year to me. I officially became a PhD student at ULiège. I see it as a landmark, an exciting start, and also a lot of challenges. In order to become a PhD student of ULiège, I first need to thank the Wallonie Bruxelles International, which has supported me financially. Thanks to Professor Celia Joaquim-Justo for helping me complete the procedure as well as helping me in my early days in Liège. I feel the warmth, dedication, and enthusiasm of most faculty and friends in the department. Professor Andreas has helped me a lot in approaching professional and effective working style in scientific research. Further, I have received important comments from Professor Angelique Léonard.

Fig. 1: A meeting for discussing about Khang's thesis proposal in October, 2018 with Profs. Angélique Léonard and Le Hung Anh

Zaheer is a good friend. He helped me during my stay in Belgium. We did not have more time to work together in the laboratory at ULiège. But the experience at the lab is wonderful. Nice to meet David and Junior. They became very sincere friends with me.

Fig. 2: Our group: let's smile

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Excursion to the BASF complex in Ludwigshafen

Zaheer Shariff

Every year the chemical engineering department at the University of Liège organizes an excursion for the first year engineering students to a selected company, so that the students get a firsthand experience of the different engineering domains, which will assist them in choosing their field of specialization. This year I had the opportunity of participating in the excursion to the BASF site in Ludwigshafen, Germany, which is not only the headquarters of BASF but also the world's largest integrated chemical complex spreading over an area of about ten square kilometers. A total of 28 students and 3 faculty members participated in the excursion. The journey from Liège to BASF took approximately four hours. The group arrived at the BASF visitor center at 10:00 am. The excursion was divided into three parts starting with a tour of the visitor center, visit to the acrylic monomers production site and finally interaction with representatives from process development and human resource department about their entry into BASF and their work.

The BASF visitor center is an exhibition area of about 2000 m^2, which gives an insight into chemistry using examples of the products and process that we use in our daily life. It also showcases some of the latest technological developments e.g. in the fields of 3D printing and mobility, demonstrating how chemistry contributes to latest advancements. The group was given a guided tour of the visitor center explaining how BASF makes use of simple raw materials such naphtha, natural gas, oil, water and air to produce thousands of chemicals and chemical products.

Fig. 1: ULiège group at BASF visitor center

Then, a brief introduction was given as to how BASF is adopting sustainable development and moving towards implementation of industry 4.0. The entire BASF chemical complex is synergistically planned such that the by-products of one process can be used as input to another process, thereby reducing wasting of resources, energy, and logistical costs. The chemical complex is a city in itself with several amenities for employees like dry cleaning, salon, and fitness center on site, also there are several bus lines to transport the employees within the complex. After the tour of the visitor center, the group was invited for a sumptuous lunch at the central canteen on the chemical complex, the Red Ox.

After lunch, the student group visited the acrylic production site, which is situated at the center of BASF. The visit started with a brief presentation about the production of acrylic acid and the monomers followed by a tour of the plant. It was an excellent experience for the group to see the life size reactors, evaporators, extraction columns and other equipment. The highest platform at about 32 meters near the extraction column gave a splendid view of the entire area.

The excursion concluded with presentations and interaction with the representatives of BASF. The representatives of BASF spoke about their journey as to how they came to work at BASF starting from their choice of studies and interviews to their current portfolios. Further a representative of the HR department explained the opportunities for student internships and different ways of starting at BASF and also the various levels of hierarchy at the company.

Acknowledgements

We are thankful to Dr.-Ing. Florian Buchbender, a former member of the Pfennig group now working at BASF, for the organization and planning of the excursion, and our dean's office for the organization on ULiège side.

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Group Outing: Surrounding the Lake of Eupen

David Leleu

On 11th of August, our group went to an excursion around the water reservoir of Eupen for the annual group outing. The lake of Eupen is located 50 km from the University of Liège and is actually a water reserve of 25 million of cubic meter of drinking water. The lake is located at the border of the highest plateau of Belgium called the “Hautes Fagnes”. The soil of the region has the particularity to be rich in Iron. It affects the taste of the treated drinking water and gives a reddish color to the water of the lake. The latter is surrounded by forests with a variety of trees and bushes. This makes the perfect place for a group outing. The goal of the day was to walk around the lake for a total of 14.5 km.

Zaheer with his family, Junior, and I, joined by Andreas and his wife, Claudia, drove until the barrage to begin our journey at the top of the dam.

Four hours of walking during a half-cloudy, half-sunny afternoon were necessary to complete the surrounding. We enjoyed the crossing of hardwood and pines forests with a nice view on the lake. We saw several flowering bushes and we also got experience on wild fruits, like berries, and flowers picking. Unfortunately, we were not able to observe animals even if deer’s and boar are present in the woods surrounding the lake.

Around the lake, there are several rivers which feed the reservoir. One of them was the perfect place for a break with a short snack, as shown in the picture.

The group outing gave us the opportunity to meet in a relaxing environment and to learn to know each other better.

My wife joined us at the end of the day at Andreas’ home. We enjoyed a vegan menu, cooked by Andreas and his wife. To the menu: zucchini soup, falafel with vegetables and chocolate mousse. The night was complemented by relaxing chatting.

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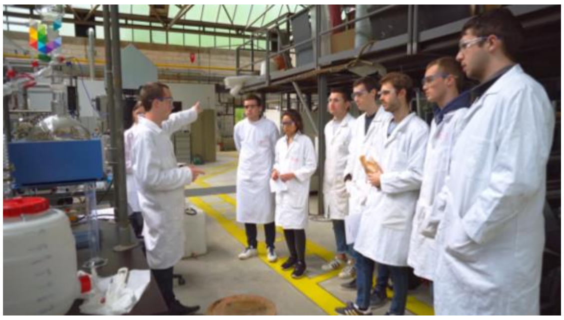
Schnaps on YouTube

Andreas Pfennig

Meanwhile the production of schnaps has been realized more than twenty times to apply Chemical Engineering knowledge to a useful example together with students. Also this year schnaps has again been produced, where the students decided to use apples as raw material. This time, the duties of the students were slightly extended, since the documentation should not only be realized as website as in the last years, but also as video. The video production itself was supported by the communications department, specifically Mr. Remy Hespel, who made several interviews with the students and participated in a variety of meetings as well as in the excursion to a local distillery. He also produced the final video, which very nicely combines several layers of information:

- it is a serious task to apply Chemical Engineering expertise designing and operating a specific process, even schnaps production,
- the objectives and applications of Chemical Engineering in general,
- and that it can be fun to realize a process practically.

This video even made it to the front page of the ULiège website in the news section! And here it is finally, the link to the video:
www.youtube.com/watch?v=Hff15tZTEv8.
The report on the schnaps project is of course again the website that was created by the students, including all relevant information:
www.chemeng.uliege.be/schnapps.
Finally of course the statement should not be missing that also this year the quality of the final product has been excellent, which of course influenced the grade for the course. The grade on the other hand includes also a certain fraction of mutual self-evaluation among the students, which allows to slightly reward students, who are getting highly involved and who work reliably as seen by their colleagues. The schnaps project, which is elective in the Bachelor curriculum, will thus again be realized in the following semester. The number of students has been continually increasing and will be 22 for the new project starting in February.



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Cookies and X-Mas Lecture

Andreas Pfennig

For the second year the regular events that were a tradition in my previous affiliations have now been re-established, namely the baking of Christmas cookies and the Christmas lecture. The Christmas cookies that were selected are

- Chocolate Brownies,
- Vanillekipferl,
- Kokosbusserl, coconut macaroon, and
- Florentiner.

This year we were supported also by Martine Lovato, one of the secretaries of the department. The difficulty to find appropriate translations into English shows already that baking of cookies for Christmas is apparently a tradition with local boundaries. Already in Austria, the names differ, while the types of cookies are rather similar to German traditions. Thus a German 'Kokosmakrone' is 'Kokosbusserl' in Austrian, where 'Busserl' means little kiss. There are additional quite subtle differences between Germany and Austria in the cookies tradition. While in Germany the cookies – at least those the author knows – have a decent size, in Austria, the housewife (sorry, but I have not met other men, who exchanged their views on making Christmas cookies) seeks to make Christmas cookies as small and elegant as possible.

Our cookies are then part of the Christmas atmosphere, which we try to induce at least a little bit during the Christmas lecture, in which the group members present their research in general terms together with some aspects of the latest findings. This is one aspect to show a little that Chemical Engineering is not just the professor teaching the subject, but that there is on-going research behind it. Also this lecture is the opportunity to get into contact with the students and exchange e.g. about the Christmas traditions. In Belgium, Christmas cookies are essentially unknown – at least in Wallonia. The students agreed that there is only one local traditional Christmas cake, namely Bûche de Noël. This is a biscuit roll with a chocolate cream filling, which is decorated to closely resemble the trunk of a tree. Of course there are also common traditions between countries, like Glühwein, which in French is simply and very unromantically called vin chaud, which is of course also offered at the Christmas lecture.

If there are cookies left over, these are then contributed to the department Christmas lunch, which until now still is called such, where I remember that in Germany more than ten years ago there were already heavy discussions on how to call this event in a multicultural globalized environment.

plates with our cookies at the department Christmas lunch

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Teaching in Oman and Thailand

Andreas Pfennig

As already during many years meanwhile, lectures have been given in Oman and Bangkok. At GUtech in Oman the lecture is the basic lecture on separation processes, at TGGS in Bangkok it has been the advanced lecture on process intensification and hybrid processes. Even though the time of the stays is always short, due to the intense interaction during the block course a rather intense interaction with the students is regularly achieved, which is a good basis for a fruitful transfer of knowledge. Due to the different background in each country there are also challenges to be mastered, e.g., if the students don't know the ternary diagram from thermodynamics, which is required to present the Hunter-Nash method for extraction. But meanwhile this does not come as a surprise any more, so that suitable chapters have been introduced and a corresponding YouTube video has been prepared. A very special event during these courses was the visit to 'The Vegetarian Cottage', where traditional Thai food is served, but everything is purely vegan. What a delight! The photos may tell more than 1000 words.

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An up to date list of publications is available at: https://orbi.uliege.be/ph-search?uid=U222548

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A Last Word

an undisclosed student

Explain briefly how absorption works.
Which phases are contacted and in which direction occurs the mass transfer?

the mass transfer occurs from ~~left~~ right to ~~right~~ left. ?