Intelligent control of swimming pool disinfection with reduction and treatment of harmful by- products

Reporting

Project Information

INTELLIPOOL

Grant agreement ID: 605804

Status
Closed project

Start date
1 September 2014

End date
31 May 2017

Funded under
FP7-SME

Overall budget
€ 2 297 011,60

EU contribution
€ 1 775 481,60

Coordinated by
SKJOLSTRUP & GRONBORG ApS
Denmark

Final Report Summary - INTELLIPOOL (Intelligent control of swimming pool disinfection with reduction and treatment of harmful by- products)

Executive Summary:
The INTELLIPOOL project funded by the EU under the funding scheme FP7-BSG-SME ran in the period from 1/9-2014 to 31/5-2017. The project was proposed by a group of four European SME suppliers of water purification and monitoring/control technologies with a common objective of developing and demonstrating the technical and commercial viability of a highly innovative, intelligent treatment and control concept for treatment of swimming pool water and indoor air, with much less impact on natural resources compared to traditional systems. To achieve the project objective and overcome the complex scientific barriers, the four SME suppliers made contract research agreements with 4 RTD performers with

high-level scientific knowledge in topics related to the required technology and concept development.
A range of fundamental research activities was initiated to provide a solid swimming pool system knowledge platform for the technology and control system development. The knowledge platform provided results on the link between bather load and input of anthropogenic contamination in swimming pool environments including establishment of overall mass balances and identification of specific precursors of disinfection by-products and kinetics of DBP formation. Controlled studies on chlorine disinfection lead to the definition of lowest necessary chlorine concentrations to ensure high microbiological safety in swimming pools. The knowledge platform also included results on hydrodynamic modelling of pool water and air for optimization of contaminant transport and setting requirements for treatment technology. The fundamental system knowledge was integrated into a numerical mathematical model both working in water and air for advanced design of treatment units for a given swimming pool system. Also, a specific software tool working only on air was established to develop new control algorithms for energy efficient ventilation systems.
The fundamental system knowledge provided the SMEs with a framework for the individual treatment technology development activities in the project. Significant technology development work was undertaken and a range of new foreground knowledge was established on optimization and design of chlorine electrolysis systems, particle separation in drum filter technology, removal of combined chlorine by UV-technology, removal of volatile disinfection by-products in air-stripper technology, removal of air-bourne disinfection by products from ventilation air by photocatalytic technology and use of advanced sensor technology for monitoring and control of water quality and technology for water and energy savings.
Based on the models and the individual optimization results of each core technology, the complete treatment and control concept was designed and build at a large public swimming pool facility in Sjöbo, Sweden. After an 8-month run-in period of the entire system, a comprehensive monitoring program was undertaken at the site to make an in-depth documentation of water quality and operational costs. The results showed that the developed concept delivered constantly excellent water quality independent on high bather load incidents an in addition the developed control system could save at least 20% of total energy consumption in the operation by turning the UV-technology on and off and by lowering the total circulation flow of the pool water without any negative effect on water quality.
At the completion of the INTELLIPOOL project, the four SME suppliers have achieved significant exploitable new foreground knowledge of swimming pool systems and technology that are at a stage of near commercial development into products and services. This will help the SMEs become profitable and the development of new commercial activity will potentially improve the labor market by creating new jobs after completion of the project. Thus products/solutions will have the potential to create impact on the economic and social sphere.
Project Context and Objectives:
Contextual background

Common-use recreational bathing facilities are growing in numbers in the EU fueled by the public's strong interest in health and wellness. In the EU, there are now 200.000 common-use facilities1 (public pools, private spas, health clubs). The facilities are faced with the conflicting, challenge of providing hygienically and chemically safe water, and the regulators' demand for "green solutions" whilst at the same time cutting their large water and energy costs and CO2 emissions footprint. Despite this, swimming pool water treatment in European countries has not changed fundamentally since the abandonment of daily water exchange in the 1920´s and are still based on early practices adopted from drinking water treatment i.e.:

Flocculation –Sand filtration – (Activated carbon) – Chlorination.
Chlorine is a very effective disinfectant, however, it is also a strong oxidant that reacts with all other contaminants in the swimming pool water to create a variety of chlorinated disinfection by-products (DBPs). The currently used standard water treatment systems for swimming pools has thus over the last 10-15 years been shown to generate high concentrations of dangerous substances such as nitrogen trichloride, haloaceticacids (HAAs), haloacetonitriles (HANs), cyanogen chloride, chloroform, brominated trihalomethanes and other unidentified compounds, which are proven as posing severe health threats to bathers and pool side employees. The most solidly documented effects are skin irritations, “red eyes”, acute and chronic asthma-like symptoms and damage in the respiratory passage and lungs. Within drinking water treatment, the causes and mechanisms of disinfection by-product formation from chlorination has been researched for many years within the scientific and commercial community and solutions for minimization has been developed and applied.
However, within the field of swimming pool water quality and treatment, a lack of a coordinated research community has been generally lacking for decades which means that no common comprehensive knowledge platform exists that describe the link between bather load and input of particulate and soluble anthropogenic contamination in swimming pool environments including overall mass balances and identification of specific precursors of disinfection by-products and kinetics of disinfection and DBP formation. Additionally, significant lack of knowledge exists within the hydrodynamics of pool water and air that together with contamination dynamics could be used for optimization of contaminant transport and setting requirements for treatment technology.
Due to this knowledge gap, currently used standard technologies have generally failed to consider specific contamination scenarios, system level performance and potential optimization benefits that could be gained from integrated and proactive approaches, targeting minimized formation and rapid removal of pollutants rather than reactive treatment of the entire system. This has leads to costly and over engineered solutions for individual steps and total solutions that are very energy-intensive systems – mostly relying on fossil fuels and requiring large quantities of scarce water resources – and therefore have many associated costs to facility owners as they strive to comply with quality standards and hygiene regulation. Cost-saving concepts and water treatment processes for swimming pool water, that are designed based on knowledge of the actual contamination dynamics in swimming pools to target the minimized formation and rapid removal of pollutants and disinfection by-products is therefore in strong demand.

Overall and main project objectives

Based on the above the overall objective of the INTELLIPOOL project was:
• To develop and demonstrate the technical and commercial viability of a highly innovative, intelligent treatment concept which involves overall treatment of exposure routes, swimming pool water and indoor air
To fulfill the overall objective the following main objectives of the INTELLIPOOL project was defined:
• to improve fundamental scientific knowledge on the interplay between bather load and the formation of DBP’s from particulate and soluble DBP-precursors, as a prerequisite for development of innovative pool water treatment technology;
• to provide new basic scientific knowledge on the specific microbiological risks and safety of pools to enable and inform technological development with regards to needed and sufficient disinfectant level;

• to identify and asses the utility of data input and handling plus sensors and monitoring technology, which can enable real-time control and system optimization and enable proactive system intervention
• to develop optimized on-site chlorination technology with minimized chloride and chlorate input
• To develop of a full flow fouling-resistant micro-filtration technology/principle for energy-efficient particle removal to reduce chlorine consumption and DBP formation
• to develop an optimized UV technology for removal of combined chlorine, adaptable to side and main stream applications
• to optimize air-stripping technology for removal of volatile DBPs
• to develop an intelligent treatment strategy using data from a smart sensor-enabled monitoring and control unit as input to a mass balance/kinetics/CFD model to empower automatic controlled optimizations and coordination of sub processes of pool sanitation for savings in water and energy consumption.
• to develop a set of guidelines and tools for modelling dynamic hydraulic and process behavior within recreation pool facilities
Project Results:
A large number scientific and technological foreground knowledge has resulted from the work in the INTELLIPOOL project. The foreground knowledge is related to swimming pool system knowledge, knowledge of single equipment as well as knowledge integrating software solutions. The main S&T results/foreground will be presented below:

Main foreground achieved on indoor swimming pool air hydraulics and ventilation:
A significant advancement of knowledge on indoor swimming pool air hydraulics and distribution of disinfection by-products and their dynamics with bather load was achieved. Additionally, a deeper understanding of conventional ventilation parameters such as water evaporation, humidity and CO2 has been acquired through modelling and experimental work. Furthermore, significant advancement has been achieved in the field of ventilation air treatment in terms of removal of volatile disinfection by-products from the ventilation air. All the acquired knowledge has been collated and integrated into a software design tool that can be used in the development of new control algorithms for energy saving operation without compromising a good thermal comfort and right humidity and also towards a chlorine byproduct free recreative environment.

Main foreground achieved on chlorine disinfection, mass balances and DBP-formation:
Substantial new foreground knowledge was achieved about necessary chlorine content in swimming pool water suggesting that much less chlorine is necessary for disinfection than is standard in most European countries. The use of much lower chlorine concentrations in swimming pool facilities could result in a general reduction in the concentrations of disinfection by-products. Also, significant knowledge progress was achieved on the understanding of mass balances of the major load compounds chlorine, carbon and nitrogen in relation to bather load. The combination of mass balance knowledge with a study of disinfection by-product formation mechanisms and kinetics has advanced current knowledge on chloroform formation. The foreground knowledge gained on system processes was been integrated into a mathematical model both working in water and air to be exploited by all SMEs in advanced design of their treatment units for a given swimming pool system. This mathematical model design approach can be a game changer for the engineers of the involved SMEs that will give them a leading edge compared to competitors in the market.

Main foreground achieved on on-site chlorine electrolysis:

Some foreground knowledge was achieved on the understanding of operational parameters governing the chloride and chlorate content in the produced chlorine from the on-site chlorine electrolysis equipment produced by SME partner Electrocell Europe. The foreground knowledge lead to a change in equipment control strategy so that systems that are more energy effective, and with less salt and by-products can be marketed. Additionally, a simple steady state software model was developed that allows prediction of the resulting chloride and chlorate content of a given pool with a given chlorine consumption/bather load. These improvements of knowledge will create a good business opportunity for SME partner Electrocell Europe and be beneficial for pool owners and swimmers in general.

Main foreground achieved on particle separation with drum filters:
Significant foreground knowledge was established on the use of microfiltration with drum filters for energy efficient removal of particles. Firstly, new knowledge was established on the particle release by bathers which was included in the model to describe the particle concentration dynamics of a pool system. Secondly, the particle separation efficiency of the energy efficient drum filters was documented in full scale in detail by advanced laser-optical particle counting and sizing and showed comparable efficiency to the more energy consuming traditional sand filters although a slightly lower efficiency is seen in the separation of particles smaller than 5 µm. On the operational aspects, new knowledge was gained on the effect of continuously rotating drum on the reduction of backwash water consumption during high bather load. New innovative filter cloth material was tested in smaller scale. This material showed promising results in terms of separation efficiency where an almost 100% removal can be achieved for particles down to 2µm which is even better than traditional sand filters. The combination of new knowledge on particle release dynamics and separation efficiency provides a significant advancement in knowledge on the design of filtration systems for swimming pools. The achieved knowledge foreground will be exploited by SME partner Ultraaqua that can use the achievements to increase sales based on validated filtration systems, and cheaper more effective systems to build and operate.

Main foreground achieved on removal of volatile disinfection by products by air stripping:
Comprehensive foreground knowledge on the air-stripping process was been achieved through full scale experiments. The air-stripper was tested at different hydraulic loads, counter-current air-flow rates as well as different physical configurations i.e. varying number and distance between the perforated plates. Based on the achieved results a mathematical design tool was been developed to predict the mass removal rate of trihalomethanes (THM) of the air-stripper which can be used to design the number and operation of air-strippers in a given swimming pool installation with a given bather load. The mathematical design tool was tested and validated at a highly loaded water theme park in Denmark where two air-strippers was implemented in the water treatment system of a wave pool. The design tool turned out to be very reliable and will serve as a solid design and operation optimization tool when air-stripper solutions are to be implemented in new or refurbished swimming pool water treatment systems. The design tool as well as the obtained experimental knowledge is directly exploitable by SME partner Ultraaqua.

Main foreground achieved on combined chlorine removal by UV-photolysis:
Significant foreground knowledge was gained in the photolysis of organic chloramines by medium pressure UV photolysis. The efficiency of UV technology was tested and documented in a pilot scale test setup. Data for the fluence based degradation rate constants for the different organic chloramine species was established and used for scale-up to different capacities depending on the swimming pool system. A

numerical UV design model was setup to simulate the combined chlorine dynamics of swimming pool systems and coupled with the combined chlorine degradation rates for the UV-reactor, the model was suited to test the effect of introducing medium pressure UV-treatment. In general, the simulation tool showed that a 3kW medium pressure UV treatment is sufficient to significantly lower and maintain the combined chlorine concentration at low levels despite a high bather load. The obtained knowledge results combined with the developed design tool is directly exploitable by SME partner Ultraaqua.

Main foreground achieved on technology for removal of volatile disinfection by-products from pool air:
Completely new foreground was generated suggesting that TiO2 photo catalysis using UV-led light for air treatment is a possible road towards a technology than can remove chlorinated by-products from ventilation air. At real swimming pool environment, chloroform concentration in swimming pool air increases during the night due to the slow formation of DBPs in water and their degassing into the air. This increase was significantly lower when the pool air was treated in the UVA-LED photocatalytic reactor. CAPEX/OPEX assessment also concluded that the UVA-LED was the best alternative for irradiation source. Around 910 € and 316€/year are foreseen as investment and operational costs, respectively, using a photocatalytic treatment unit designed for treating up to 11,400 m3/h of swimming pool air. The results of the air treatment study were integrated into the ventilation model tool mentioned above and the toolkit is directly exploitable by SME partner VES in the design and sales of future ventilation systems for swimming pools.

Main foreground achieved on monitoring and control systems:
Foreground knowledge was established on relevant monitoring sensors and control strategies for operation of swimming pool water and air treatment. A monitoring prototype of selected sensors was setup for experimental evaluation to acquire knowledge on the dynamics of the different monitoring parameters in relation to bather load and based on this knowledge a second prototype of the complete control system including control algorithms was setup at the integrated INTELLIPOOL concept project site in Sjöbo, Sweden. Based on several monitoring parameters the control system could save at least 20% of energy consumption in the operation by turning the UV-technology on and off and by lowering the total circulation flow of the pool water. A more comprehensive monitoring program using advanced scientific equipment to document the swimming pool water quality based on several parameters documented the validity of the control system. The obtained foreground knowledge on relevant monitoring sensors and control strategies is directly exploitable by SME partner SWAN in the sales of their high-quality monitoring devices giving an advantage in terms of integrating with control systems and setting up control algorithms for energy savings without compromising water quality.
Potential Impact:
Potential impact including socio-economic impact and wider societal implications:
Intellipool has produced a wide range of exploitable equipment, models and results, as documented in the deliverable reports. The IP rights for the exploitable knowledge and equipment for each specific technology/product/system remain with each individual partner SME. As such the exploitation of the INTELLIPOOL results in terms of business and marketing strategy for the individual technology/product/system will be the responsibility of each individual SME partner. The integrated INTELLIPOOL concept comprising all the developed technologies/products/systems will mainly be brought to market by Ultraaqua.
The potential impact of the INTELLIPOOL project in terms of socio-economic impact and the wider

societal implications will, as a consequence of the above, depend on the market success of each individual SME partner. The benefits of each technology/product/system and the integrated INTELLIPOOL system was demonstrated and documented at a full scale public swimming pool in the project and showed significant competitiveness compared to traditional swimming pool water treatment systems. Thus, the INTELLIPOOL technology/product/system has the potential to create new commercial activity and help the SMEs to grow their profitability and through that improve the labor market by creating new jobs and make a positive impact on the economic and social sphere. Most of the involved partners is already active players on the pool business marked with solid cooperation networks and sales channels. The SMEs is strong players in each of their fields but with small or non-existing marked shares in some countries. A huge potential of the INTELLIPOOL project results is for the SMEs to get the technologies out to a bigger public, including overseas markets.

The most recent studies of the market for pool equipment and maintenance products reports data from the US and concludes that that the total number of swimming pools in the US had reached 8.6 Million (2008) and in the EU some 4 million installations. In 2011, the US pool equipment and maintenance product market reached €4.3 billion and is expected to double by 2021. The studies also report a trend towards the “greening” of the industry so the value argument of INTELLIPOOL in respect of energy saving and chemical reduction will attract what funding is available. European growth rates, driven by the German, French and UK markets has consistently been around 30% of the US market. In 2010, the revenue from water treatment equipment for swimming pools reached 650 million € in the US of which 227 million € represented water treatment equipment for commercial swimming pool segment. For the EU, the total revenue from water treatment equipment was 280 million € of which 98 million € represented water treatment equipment for commercial swimming pool segment. Newer figures from industry sources indicate the growing commercial or common-use segment tends to be resource intensive and spending much more on treatment technology than the residential segment. Therefore, a growing trend towards a more sustainable recreational sector even further highlights the commercial potential of the INTELLIPOOL solutions.
Based on the figures above, and the decided marketing focus for the SME partners, the preliminary conclusion is that the current potential European Market for INTELLIPOOL Pool Water and air treatment solutions amounts to at least €98 million – and that the annual global market far exceeds €325 million. Based on the European market alone as being an achievable target with current resources at the partner SMEs and given the advantages of the developed system, the SME partners aims for a 7% market share of new installations in year 5 post-project to be produced and marketed by the involved SMEs themselves. Moreover, a slow take-off in market share is expected, as consumers will have to gradually get used to radically new technology in this sector. From year 3 and onwards, however, growth is assumed to accelerate as network externalities kick in.

From the projected market shares and growth rates, the expected number of jobs gained from the INTELLIPOOL project, spread between the consortium members, sub-contractors and suppliers and system integrators is estimated to around 100 new jobs throughout the supply chain by the end of year 5 post project, based on current SMEs and labor intensity in the sector.
In a wider societal context, the exploitation and market success of the project results will improve the health benefits of humans and employees participating in swimming activity by improving water and air quality in swimming pool environments, thus lowering the risk of associated symptoms like red-eyes and

skin as well as asthma like symptoms. Additionally, a wide spread application of the INTELLIPOOL concept in European and US swimming pool facilities will contribute to the lowering of energy and water consumption of recreative swimming pool facilities, thus contributing to lower CO2 emission and minimizing the greenhouse effect.

Main dissemination activities:
Various methods for external dissemination was pursued during the progress of the INTELLIPOOL project such as public and scientific papers, arranging an INTELLIPOOL specific conference as well as presentations at seminars, meetings for swimming pool professionals and international swimming pool conferences.
The main dissemination activities are listed below in bullet form:

1. Web page: www.intelli-pool.eu.
2. Intellipool presentation at 11th World Aquatic Health Conference, Portland, US, O. Grønborg, October 8-10, 2014.
3. Presentation of Intellipool in the Danish magazine Svømmebadet. O. Grønborg, M.M. Klausen, G.H. Kristensen. (In Danish) December 2014.
4. Inorganic disinfection by-products: Chlorate and Nitrate and their impact on UV treatment. L. Erdinger and T. Schlosser, 6th International Conference - Pool and Spa, Amsterdam, 17-20 March, 2015.
5. Indication of anthropogenic pollutants in swimming pool water via potassium. T. Schlosser and L. Erdinger, 6th International Conference - Pool and Spa, Amsterdam, 17-20 March, 2015.
6. Desinfektion und VBNC in Schwimmbädern, L. Kreuter, T. Schlosser, L. Erdinger; Presented to the “Badewasserkommission” 13th of October 2015; at the Umweltbundesamt/Ministry of Health in Berlin, Germany.
7. Von „lästigen” Normen über den„Intellipool” zu „Geomarketing”. Presentation of Intellipool at 65. Kongress für Badewesen, AB Archiv des Badewesens 01/2015.
8. Presentation of Intellipool at „Herbstsitzungen” Anfang Dezember 2014 in Bielefeld, AB Archiv des Badewesens 04/2015.
9. Stripping of THM’s from swimming pool water. M.M. Klausen and G.H. Kristensen, Svømmebadet (In Danish), December 2015.
10. Arranging the “Symposium on improving pool water quality – Technical, microbiological and chemical aspects”, Ferry Porche Congress Center, Zell am See, Austria, May 30, 2016. The Intellipool project contributed with the following 9 presentations in total:
a. Erdinger et al, 2016, Evaluation of disinfection kinetics in swimming pools taking into account bacterial subpopulations
b. Schlosser et al, 2016, Personenbezogener Eintrag von Verunreinigungen in Schwimmbädern
c. Kreuter et al, 2016, Disinfection kinetics in swimming pool water
d. Schlosser et al, 2016, Kinetics and mass balances of chloroform formation
e. Klausen et al, 2016, Air-stripping technology for control of volatile DBPs – process modelling and full-scale investigations
f. Gronborg et al, 2016, Drum-filters – a new energy efficient filtration technology in swimming pools
g. Christensen et al, 2016, Improved chlorine electrolysis for reduced chloride and chlorate concentrations
h. Sanchis, S., 2016, Comparison of UVA-LED and conventional UVC lamps for swimming pool air treatment by means of TiO2 photocatalysis

i. Sharma et al, 2016, CFD simulation of swimming pool room ventilation with focus on energy, economy and DBP removal
11. Sanchis, S. et al (2016), Removal of Chloroform From Swimming Pool Air By Means Of Photocatalysis Using TiO2/AC Filters And UVA-LED Lamp, SPEA9 in Strasbourg, June 2016, France
12. Grønborg, O., Christensen, P.V. Kristensen, G.H. & Klausen, M.M. (2017), INTELLIPOOL - Results from a European swimming pool project - Part 1 (In Danish), Svømmebadet (In Danish), February 2017.
13. Interview of Morten Møller Klausen by Danish Broadcasting cooperation May 2017, Improved swimming pool water quality by pre-swim washing
14. Presentations at 7th International Conference – Pool and Spa, Kos, Greece, 2.-5. May 2017 the Intellipool project contributed with the following 3 presentations in total:
a. Klausen et al, 2017, Dynamic modelling of swimming pool water quality
b. Sharma et al, 2017, Optimized ventilation for indoor swimming pools by an intelligent real-time control system
c. Ho et al, 2017, Modelling the formation and degassing of chloroform in swimming pool facilities
15. Schlosser, T. Chlorination of Swimming Pool Water: Kinetics of Chloroform Formation using Indicator Compounds, ACS National Meeting, August 2017, Washington DC, USA
16. Grønborg, O., Gjedde, L., Kristensen, G.H. & Klausen, M.M. (2017), Save at least 20% of the total energy consumption by online sensor based operation, Svømmebadet (In Danish), September 2017.

Main exploitation of results:
A wide range of exploitable scientific results was produced in the INTELLIPOOL project within the field of water and air treatment in swimming pools as well as interlinked control systems. This knowledge will be commercially exploited by the participating SMEs either individually or in cooperation. The main exploitation of the project results is listed below in bullet form:
• INTELLIPOOL concept/system with components and control system, Utraaqua A/S hold exploitation rights for the INTELLIPOOL concept/system with supply agreements with other SMEs on supply of components
• INTELLIPOOL Control System, with interfaces, SWAN hold Exclusive license for European market and rights to exploit or sub-license to other markets
• INTELLIPOOL On-site electro-chlorination system, Electrocell Europe hold Exclusive license for European market and rights to exploit or sub-license to other markets
• INTELLIPOOL Improved filtration concept, Utraaqua A/S hold Exclusive license for European market and rights to exploit or sub-license to other markets
• INTELLIPOOL Improved Air-stripping technology, Utraaqua A/S hold Exclusive license for European market and rights to exploit or sub-license to other markets
• INTELLIPOOL Improved UV technology, Utraaqua A/S hold Exclusive license for European market and rights to exploit or sub-license to other markets
• INTELLIPOOL Novel air treatment system, VES hold Exclusive license for European market and rights to exploit or sub-license to other markets
List of Websites:
www.intelli-pool.eu

Last update: 26 February 2018

Record number: 219050