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DESIGN AND OPTIMIZATION OF CARBONIZED LIQUIDS IN A FILLING BOTTLE PLANT

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Abstract - *Filling is a highly automated process. Modern filling facilities operate with bottle throughputs larger than 80000 bottles per hour. The focus in the design process of such facilities is on increasing the filling rate, which could increase the bottle throughput, or in turn, decrease the number of necessary fillers in order to reduce the cost of such facilities. In case that the filling liquid is a carbonized fluid, the generation of foam can severely harm the filling process. Fillers operate usually with system pressures less than 5 bar in order to ensure that enough CO2 is still dissolved in the liquid after sealing of the bottles. During the design process, CFD codes are used to search the flow field for local pressure drops that can cause dissolution of CO2.*

The simulation of simplified bottle filler it is turned by 90 degree, thus the gravity vector is directed to the left hand side. A large storage tank is attached by a pipe to the filler that is placed on top of the bottle. The gas from the bottle interior can escape by a central pipe that guides the gas back into the upper plenum of the storage tank. The filler is designed, such that a thin liquid film is formed that flows down the bottle walls. This concept avoids a strong jet impingement which could cause strong foam formation. After three seconds of simulation time, the bottle is filled by almost 50% and the amount of generated foam is negligible small. In a subsequent design study, the geometry is modified in order to find a better design by using HEEDS with its SHERPA algorithm.

Key Words: **SHERPA algorithm, CFD codes, HEEDS.**

1. INTRODUCTION

Design or alteration of a high-speed filling system is typically accomplished through experience and testing. This has been the condition of most equipment design. Recently, however, powerful computational instruments have become available to the design engineer which makes designs and design alterations to be calculated prior to implementation. In the structural engineering field these techniques have taken the form of Finite Element Analysis (FEA), while in the fluid flow and heat transfer stage Computational Fluid Dynamics (CFD) software has transformized the design process. This paper gives the application of CFD modeling to the simulation of high-speed liquid filling. Liquid filling is among the most competiting implementations of CFD due to the need to track not only fluid motion but to also simulate the evolution of the air-liquid interface. Two case studies will be explained, one dealing with optimization of a filling line and the other dealing with evaluating a bottle design from a filling standpoint prior to construction of bottle molds or filling equipment.

Carbonated water is water in which CO2 is dissolved. It has attracted people for a long time for a lot of purposes. The original idea came from natural sparkling water. Effervescent water is produced naturally because excess CO2 in an aquifer is dissolved under certain pressure. People believed that bathing at carbonated hot springs was good for their health and healed their sicknesses. Then, people started thinking that drinking sparkling water would be more effective than bathing in it. In 1767, Joseph Priestley produced first man-made carbonated water. He found that by hanging a water bowl on a beer tank, CO2 was dissolved into water. Then he presented the carbonation method by agitating water with CO2 gas. Three years after Joseph's success, the process to pro-duce carbonated water by using a chemical reaction between chalk and sulphuric acid was invented by the Swedish chemist Torbern Bergman. This was the beginning of the commercialization of carbonated water. In 1783, Jacob Schweppes invented a sys-tem to manufacture carbonated water with high efficiency, which allowed starting mass manufacturing. He founded Schweppes Company in Geneva, which is still now one of the most famous beverage companies in the world. Sparkling water became widely spread because it gives people refreshing feeling. After that, to expand the commercial scale, flavored water was developed by adding syrup. This was the origin of the current major soft drinks brands and the huge market all over the world. The development of manufacturing methods, the filling up technology in the bottle closure, PET bottle production and carbonation technology have led to the growth of the beverage industry and made the big market in the world. As the demand of the sparkling water increased, the ma-chine with which people could make sparkling water by themselves was introduced and implemented. In recent years, this machine has become widely used all over the world especially in North America and Europe.

Currently, four different systems are mainly used to produce carbonated water in homes: In-line, batch wise, CO2 driven and Capsule. Each system has advantages and disadvantages, but the most popular system is the CO2 driven system. This is because it needs no electrical system and therefore it has a lower cost. From the point of view of the further possibility of improvement as a commercial system, this simple and low cost module has huge space for development. The machine consists of a bottle, a nozzle and the CO_2 tank. The nozzle is connected with the CO_2 tank via a tube and CO_2 gas is injected into the bottle of water through the nozzle and water is carbonated. The pressure inside the bottle is controlled to be kept around 4(bar) by a relief valve. With the current system, CO_2 concentration depends on how long and how many times the user pushes the button. However, the level of carbonation of water does not correspond to the injected CO_2. One reason for this is that during the process of carbonation, water and CO_2 are not well mixed. Therefore it can be assumed that the carbonation level is related with turbulence or mixture. In addition, small particles can be dissolved into water more easily than big particles. This is because small particles can stay in water longer than big particles because of less buoyancy effect.

2. LITERATURE REVIEW

Carbonated water is water in which CO_2 is dissolved. It has attracted people for a long time for a lot of purposes. The original idea came from natural sparkling water. Effervescent water is produced naturally because excess CO_2 in an aquifer is dissolved under certain pressure. People believed that bathing at carbonated hot springs was good for their health and healed their sicknesses. Then, people started thinking that drinking sparkling water would be more effective than bathing in it. In 1767, Joseph Priestley produced first man-made carbonated water. He found that by hanging a water bowl on a beer tank, CO_2 was dissolved into water. Then he presented the carbonation method by agitating water with CO_2 gas.

Automation of Bottle Filling Plant with Industry 4.0 by Sagar T. Payghan, Rani H. Deshmukh, Puja P. Magar,Vinod M. Manure (IJAREEIE) paper presents technical communication of automation industry which describes the technical issues of automation control system in operation development, improving management level and high efficiency process in bottle filling plant. In the bottle filling plant various processes need to be controlled and monitored regularly. Thus it becomes tedious job to handle the plant manually. PLC automates the sequence of operation to avoid human interference so accuracy is improved and speed of process has been increased. But still we require human effort. The aim of this paper describes implementation of industry 4.0 to existing real-time model of the water treatment plant using PLC. This paper is about how industry 4.0 concepts are useful in bottling industry. It's all about atomizing bottle filling industry to overcome the market demand in less time. The paper gives basic approach to move towards automation at higher level and totally digitize the industry so we can obtain efficient output in less time.

The second paper simulation of high speed filling by Christopher j. Maticestress Engineering Services, Inc. which contain Computational fluid dynamics (CFD) software is used to simulate the filling process in two case studies. The method tracks the shape of the liquid-air interface in the bottle as it is filled and indicates the appearance of splashing or a disturbed liquid surface which generates foam. Use of simulation allows the design engineer to conduct a number of "virtual experiments" before changes are made to the filling line or bottle geometry. This allows a wide range of conditions to be tested and provides a tool to optimize the filling process in a way which cannot be practically done using empirical methods.

Simulation of the filling of polyethylene- terephthalate bottles (pet) with a volumetric swirl chamber valve (vodm 40355) On the basis of calculation models and experiments byKarl hain, Harald wels, Martin muhr as changes as the bottle is polyethylene- terephthalate bottles. In this the conduction of practical experiments and an application of a CFD-modelling system in the process industry, in this specific case the beverage industry. Nowadays within the beverage industry PET bottles gain more and more market share and are widely used thus replacing bottles made of glass completely in some areas. The overall operation efficiency of bottling plants depends to a high degree on the product filling process. Therefore the research which was carried out comprises both the CFD-simulation and also the validation of results by realistic experimental data. Especially the simulation and validation of the product flow when PET-bottles are to be filled was performed, taking into consideration physical and mathematical aspects.

Another paper which include the Modelling and simulation of bottle rinsing by Claus Meister, Kai Velten & Frank-Ju¨ rgen Methner. This makes the study describes newly developed mathematical models of bottle rinsing. Our approach is based on 3DCFD models of turbulent two-phase flow (water and air), which have been implemented based on the freely available open source software Open FOAM. The models are validated using data obtained with a standard injection nozzle and then used to evaluate the performance of two fictitious modified nozzle types w.r.t. cleaning efficiency, water consumption and water drainage. Maps of the interior walls of the bottles showing the distribution of important parameters such as wall shear stresses or water coverage were derived from the simulations. The simulations suggest that rotating or pulsating injection nozzles may perform better than standard nozzle configurations.

3. CFD SIMULATION

Computational Fluid Dynamics (CFD) is the science of forecasting fluid flow, heat and mass transfer, chemical reactions, and related phenomena. To forecast these circumstance, CFD solves equations for conservation of mass, momentum, energy etc. Computational fluid dynamics (CFD) is defined as a branch of fluid mechanics which utilizes numerical analysis and data structures to analyze and to find solutions to the problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions. With highspeed supercomputers, better and efficient solutions can be achieved, and are often required to solve the largest and most complex problems. Ongoing studies provides software that improvisizes the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial validation of such software is typically performed using experimental apparatus such as wind tunnels. In addition, previously conducted analytical or empirical analysis of a particular problem can be used for comparison. A final validation is often conducted using full-scale testing, such as flight tests.

CFD is applied in a wide range of research and engineering problems in various fields of studies and industries, including aerodynamics and aerospace analysis natural science and environmental engineering, weather simulation, industrial system design and analysis, biological engineering and fluid flows, and engine and combustion analysis.

4. RESULTS

4.1 STARCCM+ Results

The process as carried out by STAR CCCM+ makes the following results. After three seconds of simulation time, the bottle is filled by almost 45% and the amount of generated foam is negligible small.

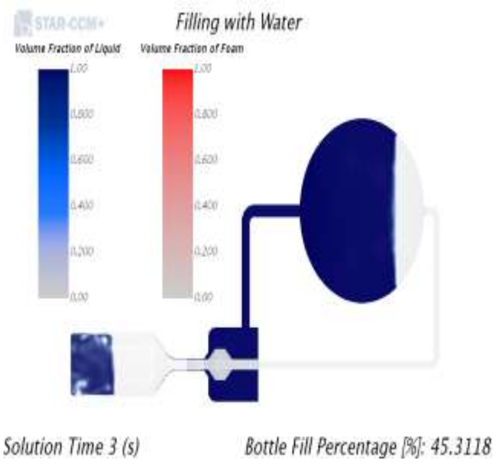

Fig: 4.1 foam factor and volume factor after 3 sec

In this case the amount of generated foam is negligible small and as a result of this we, the geometry is modified in order to find a better design by using HEEDS with its SHERPA algorithm.

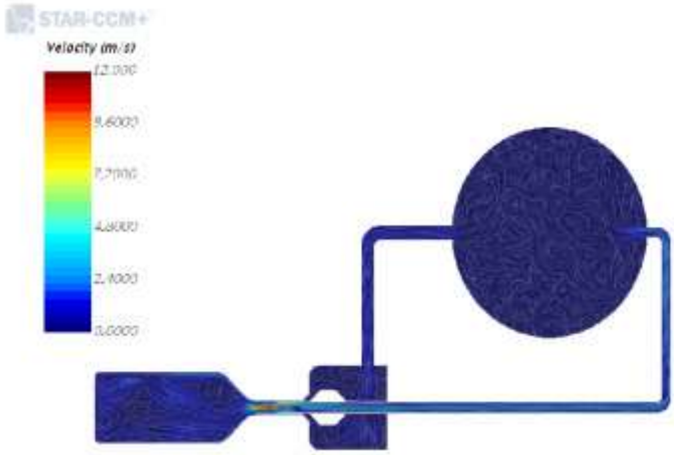

Fig: 4.2 Velocity after 3 sec

The velocity get as a value 12m/s as this mostly the center area of the bottle maximum velocity forms and the machine velocity speed is to be 12m/s. So this result is put it as the input of heeds software for further form optimization that are the following.

4.2 HEEDS RESULT

A total number of 200 designs were evaluated within 6 days using an 11 core workstation for the STAR-CCM+ analyses and a laptop for HEEDS, NX, the batch script and Excel. 30 designs were flagged as "infeasible" due to violation of the constraints. The "Analysis Details" show the outcome of each single design and the analysis timings. No error designs occurred, which indicates a very robust simulation model. Usually, error rates < 30% are not abnormal and can be handled by HEEDS.

Fig: 4.3 HEEDS parameter table

The picture above sweeps through all 200 designs and shows a parameter table, an objective history plot, a liquid and foam volume fraction scene from STAR-CCM+ and the cost calculation diagram from Excel. In the parameter table, each cell is colored using a blue-red (small-large) color map according to the parameter value range within each column. This provides a visual feedback about the parameter distribution of each design relative to the values of other designs and reveals some correlations. The objective history plot shows the value of the liquid volume fraction for each design. All current best designs are connected by a solid line, starting at the baseline design. This plot can be used to judge the convergence of the study, as the solid line asymptotically approaches a final value. The improvement between designs #75 compared to the baseline design is about 34%, whereas the improvement between the final best design #183 compared to design #75 is just about 0.34%. That means that for this study the largest improvement is found within the first 75 analyses which shows the strengths of the SHERPA algorithm.

The STAR-CCM+ scene images provide insight into the phase distribution within each design. The blue color map shows the distribution of the liquid phase and the red color map shows the distribution of the foam phase. The uncolored spaces are occupied by air. As the video shows, for some designs, a significant amount of foam is generated this can be carried by the backward flowing gas stream into the upper storage. Additionally, the foaming process dramatically reduces the filling rates and only those designs with negligible foam generation show a good filling rate. In consequence, the designs with a good filling rate appear to be cheaper for a constant bottle throughput, because the number of fillers can be reduced compared to smaller fill rates.

HEEDS provides post-processing tools for organization and visualization of design performances and parameter distributions. This is very useful for learning about mutual dependencies, trends and correlations between design parameters and responses. The correlation plot in the lower right corner of the following figure reveals linear dependencies between parameters. A self-organizing map, as shown in the lower left corner is useful for grouping and depicting a multi-dimensional design space on a twodimensional plane. Similar designs are automatically placed next to each other and less similar designs are placed more far away. Near designs are then grouped into hexagonal boxes and these boxes can be colored by a parameter, e.g. the filled liquid volume. A blue box then represents designs with a small liquid volume and a red box with a large liquid volume after 3 seconds filling time. In conjunction with a parallel plot (upper part of the following figure), the similarities and differences between those groups can be uncovered. The parallel plot shows the parameter distribution for a single design within a specific design set. Each parameter of one design is connected by a solid line. Obviously, the main difference between the "Blue" group and the other groups is a larger value for the "InOutRatio" parameter, which means the diameter ratio between outer liquid pipe and inner gas pipe. If they have an equal size (InOutRatio = 0.5), much more foam is generated and the fill rate decreases. The distribution of the "Red" group shows, that an optimal ratio is about 0.2.

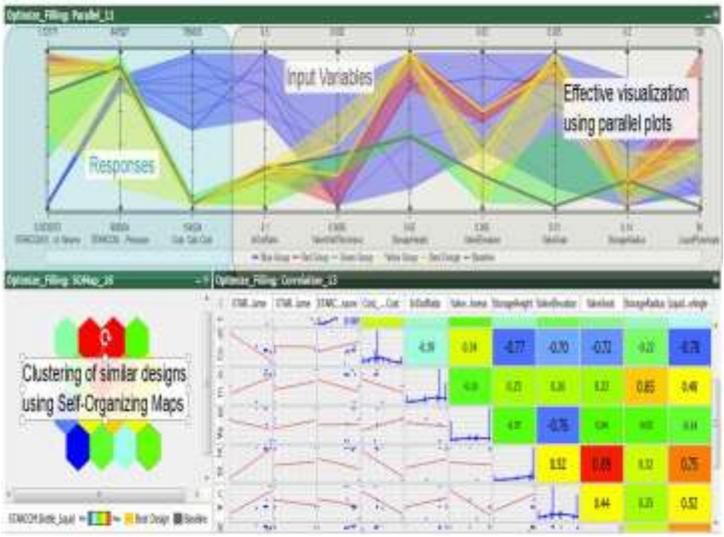

Fig: 4.4 HEEDS result visualization

In the above figure, the baseline design #1 is compared with the best design #183. The diameter ratio is changed only by a small amount, while the height of the storage tank is increased (enhances the gravity effect) and the valve size and position wais changed in order to decrease local pressure drops, because the shape of the flow channel appears now more even. As consequence, the liquid volume after 3 seconds is about 34% higher with the new design and the foam volume is 45%. All those findings can influence the design process further and are obtained within only six days.

Base line design #1		
Design parameter	Value	Percentage Increase
Diameter Ratio	0.2	-
Storage height	0.9 m	-
Valve radius	1 cm	-
Valve elevation	1 cm	-
Liquid volume	0.0836 L	-

Table 4.1 base line design parameters

Base line design #183		
Design parameter	Value	Percentage Increase
Diameter Ratio	0.208	4%
Storage height	1.2 m	33%
Valve radius	2.35 cm	135%
Valve elevation	2.05 cm	105%
Liquid volume	0.1121 L	34%

Table 4.2 Optimum design parameters iteration no: 183

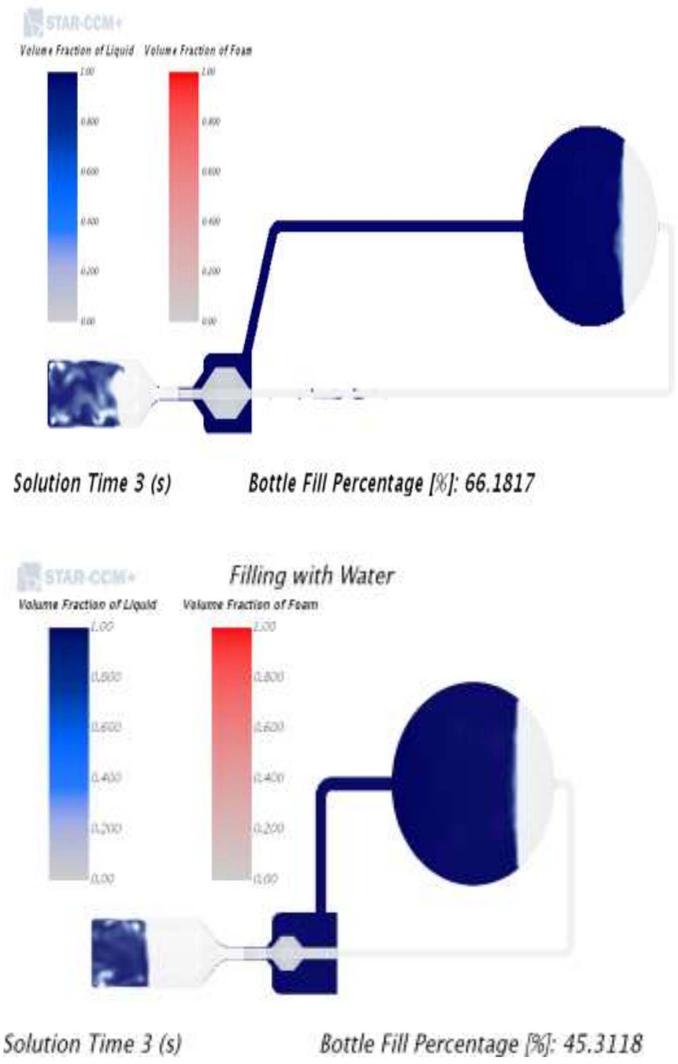

Fig: 4.5 Bottle fill percentage at optimum design

5. CONCLUSION

The use of computational fluid dynamics simulation for the evaluation of filling problems has been demonstrated in this study. These cases have used carbonized liquids in a filling bottle plant models. After three seconds of simulation time, the bottle is filled by almost 50% and the amount of generated foam is negligible small. In a subsequent design study, the geometry is modified in order to find a better design by using HEEDS with its SHERPA algorithm and to get Fill percentage increased from 45% to 66% (aprox 45.9% enhancement). And Foam percentage decreased from 7% to 5.3%. The simulations provide substantial information to guide selection of filling profiles or evaluation of design parameters.

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