A Knowledge Based Approach for Affordable Virtual Prototyping: the Drip Emitters Test Case

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Abstract
Virtual prototyping lacks of application in SME due to the costs of software systems and the necessity of skilled operators. The aim is to improve dripper emitters design process reducing costs. A knowledge base is presented to gather data on products behaviour in terms of experimental data and simulation results for a set of meaningful test cases. Input design parameters were linked to performance indices on the base of the correlations emerged in the analysis. Specifications for a new product can be used to extract similar cases and to define a possible solution in terms of a combination of them.

Keywords:
Virtual Prototyping, Knowledge Based Engineering, Design of Experiments, Drip emitters.

1 INTRODUCTION

Today companies must increase their competitiveness in the global market. In the mechanical production field this objective can be pursuit reducing time-to-market and increasing products quality. Both these aspects require an optimization of the design process.

Good product design in short time is achievable through sophisticated virtual models which represent all functional and manufacturing aspects. Nowadays, virtual prototyping technologies permit high level simulations of many design aspects: geometry, kinematics, strength, fluid dynamics, production processes, etc… Performing a wide range of such analysis on a computer, physical product prototypes can be highly reduced. That means lower costs, shorter times to market and an overall higher quality level.

However, this approach presents some problems especially for Small and Medium Enterprises (SME). These firms are often operating in low value mass products markets. Here, performance and quality are also evermore important in order to maintain and possibly increase the market share and resist to emergent countries competitors. Therefore, virtual prototyping techniques need to be effectively employed in design departments. On the other hand, SME often lack of resources and competences to effectively employ such systems. Software is usually expensive and require high skilled dedicated operators. On the contrary in a small department people are required of a wide generic knowledge in order to cope with different design aspects. That means used tools are often limited to CAD systems and product optimization is performed by time consuming trial-and-error approaches. For instance, even if the need of Finite Elements Analysis (FEA) or Computerised Fluid Dynamics (CFD) tools is recognised, costs are too high compared to product value and batch sizes.

This research work aims to develop a method to improve design process in SMEs maintaining low costs in assets and resources allocation. The objective is the introduction of knowledge base systems storing the information on a certain number of meaningful test cases. Each case is deeply analysed from a virtual and experimental point of view before being added to the knowledge base. These template products are characterised by a certain number of meaningful parameters, which are linked to main specifications. When the system has collected a sufficiently wide number of examples, statistical rules are introduced to derive new solutions in response to new specifications request. The knowledge base is traversed in order to find most similar cases and the required solution is expressed from the combination of them.

The aim of the approach is to limit the cost of deep product analysis to a restricted number of test cases. This work can be outsourced if the company lacks of virtual prototyping tools or test machines. Once sufficient data has been gathered, a knowledge base is developed and rules are established between design parameters.

When a new product instance comes, it is characterised by its own parameters drawn from requirements. Introducing them in the knowledge base, similar solutions are extracted. Using statistical rules, an attempt solution is found which is believed to be closed to the desired one. Design activity is then limited to optimization and physical prototyping. Since the attempt solution benefits of previous results, it requires a much shorter review process and a limited number of iterations.

As test case, a typical small mechanical company activity has been analysed. It is a plastic moulding business, focused on the production of drip emitter components, used for irrigation purposes. The design and realization of such components is quite complex and requires to take into account many different functional and production aspects.

The long term objective is a knowledge based tool to support the design of these particular devices. It needs a multidiscipline approach since it gathers data on product specification, geometrical layout, numeric simulations, production choices, experimental tests and customer reports. The tool elaborates specifications input, such as water discharge and geometrical constrains, maps them to knowledge base and it comes up with a suitable design.

1.1 Drip emitter description

The drip emitter is an important device in water-saving agriculture, and it characterizes all development of modern agriculture. The use of dripper emitter is fundamental in arid regions or where rain begins to decrease. The task of this component is to dissipate pressure and to deliver water at a constant rate by lowering the pressure energy. Shapes are various as shown in figure 1. Usually dimensions are very small, and the water flow crosses through micro-orifices like a labyrinth channels which make the pressure drop. Discharge rate is usually 1 to 8 L/h and is linked to the small width and depth of the flow path which is about 0.5 to 1.5 mm high.

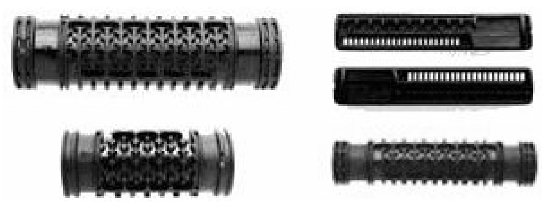

Figure 1: Various design solutions for dripper emitters

Drippers are equally spaced inside irrigation lines which are laid on the ground or just few centimetres below the surface level. During pipe extrusion drippers are welded toward its inner surface. Pipe diameter is around 16 mm and its thickness varies between 0.12 and 1.5 mm. In agriculture many pipe-lines are used and the intake pressure is variable. In horizontals fields, nominal pressure is 1 bar, while in sloping fields pressure can reach even 4 bars in lower level areas (figure 2).

There are two big families of drip emitters: the flat dripper and the round type. Each of them can be divided in two subfamilies: unregulated dripper and regulated dripper. The flow rate in unregulated dripper varies with inlet water pressure. On the contrary, regulated emitter maintains a relatively constant flow rate at varying water pressure, within the limits specified by the manufacturer. Last ones show good performance in sloped fields where intake pressure is inevitably variable.

Figure 2: Dripper emitters in irrigation lines

The most important properties in drip tubing irrigation systems are uniformity, anti clogging capacity and life-span of all components. A well designed dripper device should maximise these aspects and ensure a good hydraulic performance.

Uniformity is the property of each dripper of a piping line to provide almost the same discharge rate in a range of ±10%.

Anti clogging capacity is the property of an emitter to reduce the precipitation of suspended particles. In fact, these devices can easily clog. Efficient turbulence can create some reverse whirlpools in low velocity zones and this effect prevents the sedimentation of suspended particles. Another method to reduce clogging is the introduction of a filter at water inlet section. This filter is often made of a grid which blocks particles larger than a third of the labyrinth smallest cross section.

Dripper life is linked to the plastic material used to produce this device. Many producers employ only thermoplastic materials. Most of them are made in high density polyethylene, because this choice is an important compromise between physical and moulding properties.

1.2 Current state in drip emitters design

Drip emitter design process is commonly based only on the experience of engineers supported by CAD-CAM systems and trial-and-error procedures. Nowadays Computer Aided Engineering (CAE) systems can be successfully employed to investigate performance of emitters without any physical realization of physical prototypes.

In particular, CAE systems include Computational Fluid Dynamics (CFD) software, which is useful to calculate hydraulic performance of the emitter such as the output flow rate and the pressure drop in the labyrinth. On the other hand the production can be analysed with the help of moulding simulation systems in order to investigate product integrity, mould cycle duration and efficiency.

The integration of virtual prototyping tools in the design flow is very important in shortening the whole production cycle. However, some specific knowledge is required for a correct interpretation of the results. CFD outcomes highly depend on the geometry but the last one is not so certain.

In fact, nominal CAD model differs from effective dimensions of a real dripper assembled into a pipeline. The extrusion process, used to form the pipe and stick the dripper, creates a permanent junction between the parts. The dentate path penetrates into the internal face of the pipe and the actual depth of the channel reduces. The effective correct depth is not easily predictable, because it depends on the type of materials, geometry, external pipe thickness, extrusion temperature, speed of the extrusion etc.... Therefore CAD/CAE systems outputs must be matched with experimental tests in order to draw correct results.

2 STATE OF THE ART

In this paragraph a brief review of the state of the art related to this research is outlined. In particular Knowledge Based Systems, Design of Experiments Method and approaches in drip emitters fluid dynamics are presented.

2.1 Knowledge Based Systems

Knowledge Based Engineering (KBE) is a technical domain that includes methodologies and tools to acquire, formalize and represent in IT systems the knowledge of a specific application field. KBE is a special type of Knowledge Based System with a particular focus on product engineering design and downstream activities such as analysis, manufacturing, production planning cost estimation and even sales. The development of such applications aims to shorten the time of products configuration phase, to aid in decision-making activities and to automate repetitive procedures.

Nowadays, many companies try to invest in KBE systems. Configuration is often applied in consolidated productive situations to standardise functional groups and improve economies of scale. By means of a suitable analysis, it is possible to determine product platform for future production. Further development is represented by variants definition through the assembly of "intelligent" modules that encapsulate the configuration rules and the design parameters.[1]

However, this research is focused on those cases whose final solutions can not be explicitly detected only on the base of specific design parameters. Here final configuration is the result of many design activities. The impact of each single selection or choice needs to be assessed in terms of costs, performance, assemblability and so on. In absence of decision support tools such task, generally, is intuitively performed on the basis of the expert's personal skill. In order to evaluate alternative solutions, the designer must be able to manage the different types of knowledge that are part of the configuration model knowledge.

The goal is to develop a system to support the expert during his/her decision-making activity. Then, the problem to formalise, integrate and structure different types of knowledge involved in both the design for configuration and configuration of the solution phases is a crucial point.

The implementation of this support tool requires knowledge relative to the product domain. This knowledge can be at least classified in two kinds: explicit knowledge and tacit knowledge. The explicit knowledge is rational and sequential, and can be found on books, manuals and catalogue. On the contrary, tacit knowledge is more linked to the individual experiences, so it is very difficult to describe it. Knowledge is mainly drawn from the development team, made of people with different tasks and composed by internal and external collaborators. In SME some competences cannot be found due to the reduced internal staff. So it is important to formalise and store this knowledge in order to avoid continuous expenses for outsourcing [2][3].

Knowledge recovery should be carried on in order to gather information without slowing down enterprise activities. In this analysis phase, the base for future development is established, since rules and tacit knowledge are collected. Then, the phase of development follows. The experts team defines the tasks and implements a methodology and related tools. The third step is the systems test, in which they start to be employed in the design department.

2.2 Design of experiments method

The Design of Experiments method (DOE), which was developed by the mathematician Ronald Fisher, is used to determine the relationship between the different parameters (Xs) affecting a process and the output of that process (Y) involving structured data matrices [4]. The advantage of a DOE tool is linked to the acquisition of the tacit knowledge which is normally based only on designer experience.

This method involves some steps: definition of objective, the choice of a number of experiments (better if small), definition of input and output variables. It requires designing a number of experiments in which the principal variables are varied. Analysing the results, it is possible to find the optimal solution of a problem, the dependent and independent variables and the relations between all parameters.

In the areas of research and development, DOE is fairly widespread, but sometimes this method result expensive, so to contain costs it is wise to do few experiments as possible. The DOE approach requires the identification of influencing parameters in the problem. Since each experiments costs time and money, it is recommended to ask whether these experiments are really needed, so a minimum number of them should be organized and performed. Instead of beginning with randomly changing design parameters, DOE method distributes the experiments nodes as uniform as possible. With this methodology, costs and results deviations can be calculated in advance.

2.3 Dripper fluid dynamics related works

Recently some researchers studied the fluid dynamics in the dentate path with many numerical and experimental methods. However, these studies are often pure computational fluid dynamics simulation of the flow inside the labyrinth channels. In fact, the main objective is the verification of the presence of a turbulent flow. On the other hand, there are not many research papers focusing on the behaviour of the dentate path and the influence of the geometry on the discharge rate [5][6][7].

There is an important study around the Reynolds numbers inside the labyrinth. In fact, if the particular dentate geometry has not yet been analysed, there is no actual knowledge of critical Reynolds number, that fixes the transition from laminar to turbulence flow [8].

For Kamrmli [9] the critical Reynolds is almost 2000. Maintaining fluid dynamics conditions over this value, the flow can be considered turbulent providing energy dissipation inside the path and anti-clogging effect. The effects of reverse vortexes along the path where shown in the work.

From an experimental point of view, it is pretty difficult to measure the effective Reynolds in a path almost 0.8 mm width. So, many authors rely only on CFD simulation results. Zhang [10] made an experimental setup to measure flow using a Laser Doppler Velocimetry device with magnified model in plexiglas (dimensional ratio 15:1) according to the Reynolds number similarity method.

3 PROPOSED APPROACH

The aim of this work is the development of a framework for the implementation of knowledge based applications to support the design of products requiring complex virtual and experimental analysis.

The steps to come to a valid knowledge base to be embodied in a support tool can be summarised as follows: an investigation phase based on dialog with customers and suppliers, a research about the product, the application of virtual prototyping tools, the study of production and assembly process, materials, and finally the study about particular experimental set-ups.

The principle of the approach is recognised in the DOE method. Characteristic input and output parameters are used for the specific problem and test cases in the knowledge base play the role of the experiments [11].

After data has been gathered, it needs to be stored in a system following the steps here listed:

Targets individuation: it is the definition of the principal objectives of the study;

Input parameters individuation: it is the analysis of all variables on which the problem depends. These parameters can be divided in geometrical, physical, process and operating parameters. They respectively represent physical constraints, material properties, production processes parameters and parameters linked to the operating conditions;

Output parameters individuation: these parameters are affected by changes in input ones. So these variables are part of the specifications and must be experimentally verified. They can be divided into functional and quality parameters.

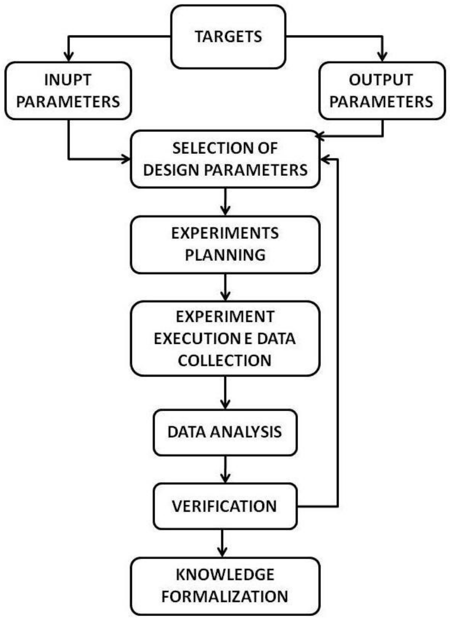

Figure 3: Diagram showing the proposed approach

Selection of design parameters: only parameters which mostly influence the study are analysed. Parameters reduction permits to save time and money in the next steps. This selection must be justified to guarantee analysis consistency. As result of verification step these parameters may be changed.

Experiments planning: this step is important to predict analysis duration and cost. It is recommended to reduce experiments number to the essential ones. This phase can be integrated or substituted by virtual prototyping technologies.

Experiments execution and data collection: this phase is based on experimental setups and measures operations. All data must be organised in a structured database.

Data analysis: it is the central step in which the virtual and experimental results are used to find rules and conditions. So this phase is liked to knowledge caption. The output is a first attempt theory.

Verification: here theoretical assumptions and their correctness are verified. This step can bring back to the selection of design parameters.

Knowledge formalization, is the final step in which the product knowledge is formalised in terms of parameters correlations, so it is ready to use in a similar problem.

Once data is acquired and knowledge formulated, a tool to support design process can be implemented. The core of this support tool is a structured multidiscipline database that is the collection of all design aspects of the analysed test cases and rules to link input and output parameters.

A specific design solution is then extracted recognising product category and similar test cases. Then parameters correlations and rules are used to predict the product behaviour.

4 DRIPPER EMITTERS DESIGN PROCESS

The proposed approach has been tested on the design process of dripper emitters used in irrigation applications. The research program has been funded by and carried on in collaboration with F.G.R. srl, a small Italian company operating in the moulds design and production for plastic components.

4.1 Drippers design process

The research is focused on drippers design and production. Companies define the exact shape of drippers on the base of specifications and then design and produce injection moulds for their realization. Usually they sell the product, but sometimes only moulds. Above all, they provide a specific dripper design service.

Dripper production follows the mass customisation paradigm, today highly diffused in the modern globalization. The dripper is not a standard product and customers are represented by pipe producers. These firms buy drippers which are inserted in the pipeline during the extrusion process. Every customer requires different specification based on the specific irrigation application and the technologies being used to manufacture the pipeline.

When a new order comes, it specifies some overall dimension requirement, a specific flow rate, a certain intake pressure, specific environmental working conditions and other functional requirements. All these variables lead to the necessity of a new design which often may be similar to a previous one. However this does not mean that the design process can be fully recovered. Small changes require the repetition of all the design, manufacturing and testing steps as pointed out as follows.

Currently the time for designing and realising of the final prototype of a drip emitter is quite long (almost 3 months) and it includes four steps: the design of the emitter, the project of injection moulding process, the assembling process between dripper and external pipe, and the experimental set-up of the emitters pipelines (figure 4).

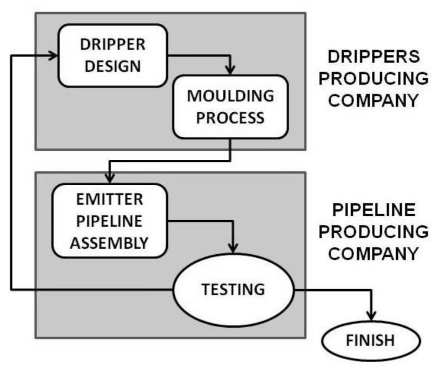

Figure 4: Diagram showing dripper design phases and iterations between companies

An initial wrong design could highly increment the cost of all the realization process. For instance, negative results from the experimental set-up require a product revision and the repetition of all the design and manufacturing steps. Moreover, drippers are usually designed and produced by a firm while they are assembled by pipe producers. That means the overall time for iteration is long and the all design process could span for months.

The first design step is the most complex because engineers must considerate at least four fundamental aspects: fluid dynamics, geometrical and dimensional constraints, influence of geometry into moulding process and the choice of materials.

A new project begins with the analysis of the geometrical constraints. Overall dimensions depend on different extruding machines which include drippers in pipeline.

Each of them makes use of a particular track to convey the emitters: so it is not possible to standardize product geometrical limits.

Secondly, the designer must fulfil customer fluid dynamics specifications. In particular, every dripper has its own characteristic discharge rate, linked to a particular agricultural application. This parameter is very critical. There are no rules or methods to analytically compute this value due to the complexity of the geometry.

CFD simulation may be employed but there are many parameters influencing the results. It is important to know them precisely in order to come out with good results.

That means the designer usually bases his work only on experience. At first he fixes a possible labyrinth path. Then he works only varying the depth of the channel. In choosing the geometry he must take into account anti-clogging properties, life-span of the parts and overall performance. A dentate design is usually preferred since it meets these two aspects. The profile is often triangular since it guarantees a turbulence flow to increase pressure dissipation and to prevent sedimentation of suspended grains. In addition, an intake filter is added to stop bigger particles.

After geometry definition, the moulding process is designed. Main aspects are related to lines productivity and the correct and constant properties of the product. This is very important for the quality of dripper pipelines, because every dripper must emit almost the same water quantity to guarantee a balanced irrigation of any plant of the field. The discharge uniformity is a central parameter the designer must control in all the process.

Besides, the realization of moulds requires many types of machine tools, such as copper electrodes and mills with an accuracy of about 0.01 mm. The compromise between performance, cost and fast realization is hardly reachable and requires knowledge linked to the experience.

After a pilot batch has been obtained, the customer tests a first assembly-line to experimentally measure the effective discharge rate. Results are often not very good, so the first dripper model may need a deep revision and the repetition of all previous phases. This leads to a trial-and-error loop which terminates only when the experimental results are sufficiently good. This loop spans in all production steps, so it is very expensive for the company which needs to employ many resources to realise changes to the first dripper design.

5 A KNOWLEGDE BASE FOR SUPPORTING DRIPPER DESIGN

In this paragraph the problem of the construction of a knowledge base for a dripper design supporting tool is addressed. Some meaningful test cases are examined both from a virtual and experimental point of view. This information is used to extract main design parameters and their correlations.

5.1 Dripper design parameters

To test the introduced methodology, two different cases from the flat and the round dripper families have been analysed.

The input parameters, which influence the performance of all the drippers, can be divided in geometric parameters, such as dentate path shape, path depth, pipe thickness; process parameters, such as moulding pressure, moulding temperature, assembly process temperature; dripper and pipe material properties; operating parameters as water pressure, water temperature and clogging state. The output parameters can be mainly recognised in discharge rate and lifetime. All these parameters are numerous, heterogeneous and complexly linked.

Here some hypotheses follow which where formulated to simplify the approach. The study was focused on geometric and on operating parameters. Factors linked to material and moulding process where considered as constant. Material was fixed in high density polyethylene both for the dripper and pipe; operating temperature and clogging state where respectively fixed in about 23°C and in the absence of any clogging sediment. As output parameter, discharge rate was only taken into account while lifetime has been ignored since it mainly depends on chosen material and employing conditions.

In the test cases a constant pressure of about 1 bar was fixed and the attention focused on geometrical parameters, such as the dentate path geometry and the path depth, which deeply influence the dripper performance.

Generally speaking, parameters are chosen out of convenience considerations. New design very often new design starts from an existing model which maintains most of the geometric choices such as structure, labyrinth shape, inlet position, and so on…. For that reason a new design is often based on a product family choice and then concentrates on parameters such as path depth, overall length and number of labyrinth bends which, conveniently varied, lead to desiderate performance.

5.2 Chosen test cases description

Three kind of flat drippers, characterised by three different dentate labyrinths where analyzed. Moreover, for each flat device three different path depths were considered. All the dripper have were also experimentally tested on pipelines of different pipe thickness.

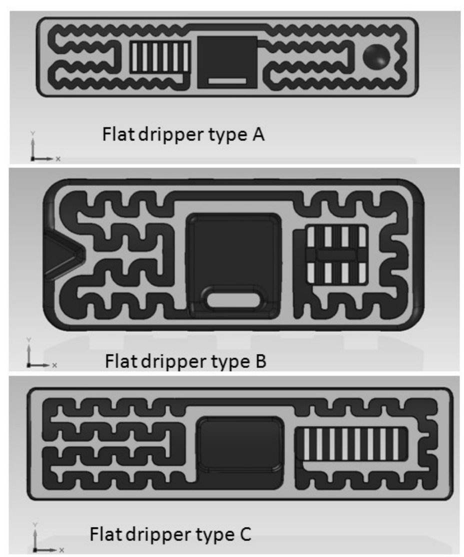

Figure 5: three type of dentate paths being analysed to study the flat dripper (flow path is dark)

In particular, external dimensions of the flat drippers respectively are: 35x8 mm (flat type A), 20x8 mm (flat type B) and 30x8mm (flat type C). The path depth varies between 0.75, 1 and 1.25 mm. Finally the thickness of the assembly pipe, on which the drippers were installed, was chosen in 0.15 or 0.3 mm.

In figure 5 the three types of path are shown. At first sight, it may be observed as the first path is long but each dentate tip is very rounded; the second path is very shaped and finally the last path has an almost rectangular dentate module. After simulations and experiments, it is possible to discuss about the influence of geometry design on the discharge rate.

On the other side, round emitters have cylindrical symmetry, so are pretty different from the flat type. The approach being used is the same of the flat ones. So three labyrinth types were chosen (see figure 6), but in this case only the pipe thickness were studied, varying between 0.7, 1 and 1.2 mm. Besides, channels depth was been maintained fixed.

Pipe thickness effect is here more evident than in flat drippers. This is mainly due to cooling phase after pipe extrusion. Radial tension make the dripper weld to the pipe with partial materials overlapping. A thicker pipe will cause stronger tensions and therefore deeper material deformation. As result, labyrinth channel effective cross section will be smaller then nominal one.

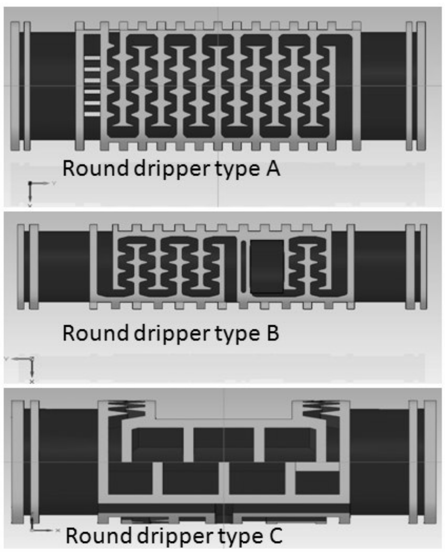

Figure 6: The round dripper chosen as second test case (flow path is dark)

The external diameter of these emitters is 16 mm, while lengths are 50, 40 and 35 mm. All three types have nominal labyrinth depth of about 0.8 mm.

As happens for most designs, two parameters were investigated: path depth and pipe thickness. The last one is not a strictly related dripper design parameter but highly influence the results so can be considered as one of them. Other parameters were maintained constant among homogenous product families.

5.3 Product virtual analysis

Chosen dripper models were both experimentally and numerically analysed. Fluid dynamics aspects were simulated with a commercial CFD system, Fluent by Fluent Inc. All geometries were meshed with grids of 0.1 mm spacing leading to more than $1x10^5$ cells.

From the literature is clear how water flow into the emitter dentate path can be considered as turbulent. So, the $k-\varepsilon$ model to calculate fluid dynamics sizes was used [12].

The flow inside the emitters could be considerate as a viscous steady uncompressible flow described by these fundamental equations [13]:

Continuity equation: $$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

Navier-Stokes equation:

$$\rho \frac{\partial u_i u_j}{\partial x_i} = -\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_i}\left[\mu_e\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \qquad (2)$$

Gravity and surface roughness effects were neglected.

In the simulation standard boundary conditions about flow inlets and outlets were set. Relative pressure at inlets were set to 1 bar, corresponding to normal emitters working pressure, while at the outlets pressure was fixed to zero. The outcomes of numeric CFD analysis are reported in the following paragraph.

5.4 Experimental tests

The experimental phase was consisted in the design of the moulds and in the realization of the different flat and round drippers discussed above. Then tests were carried out to measure output parameters.

Figure 7: The test dripper machine

The data were gathered in two different ways: with a standard discharge rate measurement of some extruded emitter piping and by means of an innovative test machine. Since the discharge depends on the type of pipe, the second test was designed to simulate the tube interference effect. Basically, a silicon cylinder encloses the dripper and let the water flow into the labyrinth. A particular of this machine is reported in figure 7.

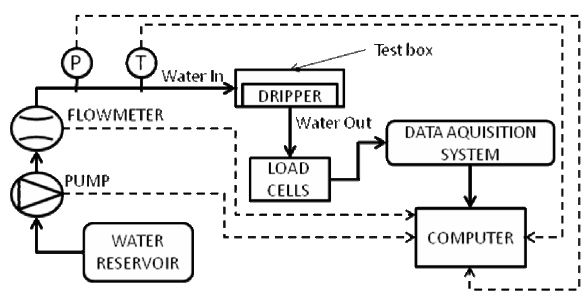

Figure 8: Schematic diagram of experimental set-up used in measuring the discharge rate of drippers.

In figure 8, a scheme of this innovative dripper experimental measurement setup is illustrated. This machine can test drippers simulating the effects of the pipe, leading to time and costs savings. In fact, dripper performance can be measured before pipe extrusion.

Type	Path depth (mm)	CFD Discharge Rate (L/h)	Measured Discharge Rate (L/h)	Difference
A	0.75	1.65	1.57	11.5%
A	1	2.05	1.89	8.5%
A	1.25	2.48	2.11	12.8%
B	0.75	1.32	1.22	11.5%
B	1	1.81	1.63	10.4%
B	1.25	2.28	2.04	9.8%
C	0.75	2.52	2.30	11.7%
C	1	3.08	2.73	11.4%
C	1.25	3.54	3.12	12.2%

Table 1: Comparison between simulated water discharge rate and measured values for flat drippers.

Type	Path depth (mm)	CFD Discharge Rate (L/h)	Measured Discharge Rate (L/h)	Difference
A	0.8	3.22	2.42	33.1%
B	0.8	5.41	4.21	28.5%
C	0.8	4.14	3.12	32.7%

Table 2: Comparison between simulated water discharge rate and measured values for round drippers.

Type	Path depth (mm)	Pipe thickness (mm)	Discharge Rate (L/h)
A	0.75	0.15	1.51
A	1	0.15	1.77
A	1.25	0.15	1.95
B	0.75	0.15	1.32
B	1	0.15	1.67
B	1.25	0.15	1.83
C	0.75	0.15	2.22
C	1	0.15	2.56
C	1.25	0.15	3.01
A	0.75	0.30	1.42
A	1	0.30	1.62
A	1.25	0.30	1.85
B	0.75	0.30	1.02
B	1	0.30	1.22
B	1.25	0.30	1.62
C	0.75	0.30	2.02
C	1	0.30	2.36
C	1.25	0.30	2.78

Table 3: Flat drippers discharge rate data measured with the standard method.

Flat and round drippers were tested by means of the machine. For flat drippers nine experiments were planned, because of three different dentate paths and three path height. For round drippers three typologies of dentate paths were analysed all sharing the same depth. In the following tables experimental results are reported along with CFD outcomes.

Afterwards, experiments with the classical method for dripper discharge rate measurement were carried out. A measure station with a pump that provides water to five drip tubing has been set up. Each pipeline is one meter long, with a total of 25 drippers. These measurements are very time consuming compared with the ones realized with the test machine, but permit to analyse the effects of the pipe in the dripper performance.

For the flat dripper eighteen measure combinations were used because of two tube thickness. Besides, for round drippers additional nine tests were carried out. Those measurements are reported in the following tables 3 and 4.

Type	Path depth (mm)	Pipe thickness (mm)	Discharge rate (L/h)
A	0.8	0.7	2.32
B	0.8	0.7	3.95
C	0.8	0.7	2.98
A	0.8	1.0	2.01
B	0.8	1.0	3.45
C	0.8	1.0	2.48
A	0.8	1.2	1.92
B	0.8	1.2	3.22
C	0.8	1.2	2.21

Table 4: Round drippers discharge rate data measured with the standard method.

5.5 Design parameters discussion and correlation

Data were analysed to find correlations between input and output parameters.

Some one-on-one correlations emerged. For instance the effect of path depth on discharge rate is evident in flat emitters. The relation between the two parameters is almost linear in our test cases (figure 9). In flat dripper Type A the ratio between discharge rate and path depth is almost 2 L/h for each mm. In other terms, a depth increase of 25% causes 25% higher water flow. This behaviour can be observed on round emitters too, but in this study experimental or CFD data for it are not available.

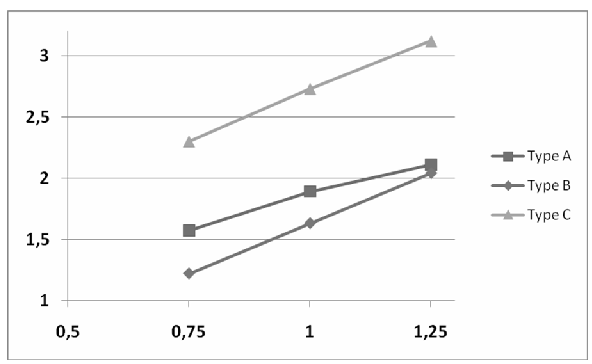

Figure 9: Discharge rate versus path depth for flat drippers

Similar is the influence of pipe thickness effect on discharge rate. In fact, especially in round emitters, a thicker pipe reduces the cross section of channels labyrinth and then make the flow rate decrease. Usually this effect is neglected and leads to problems with the pipe line assembly firms. Each customer registers different dripper performance on the base of the pipe being use and on the specific extrusion process parameters, for instance the speed rate or cooling effects.

CFD analysis shows big difference from experimental data. The gap is from 28 to 33% for round emitters and from 8 to 12% for the flat ones. Of course these errors are linked to the quality of the mesh model created for CFD analysis and the accuracy of the test machines. Moreover, CFD results also depend on some hydraulic parameter assumptions which would require further investigation. Anyway, the main reason is that CFD were based on nominal dripper geometry which does not consider the effect of pipe collapse into the labyrinth. Therefore, on test machine the discharge rate is always smaller than CFD results.

Numeric experiments should be somehow corrected considering this effect, for instance reducing nominal path depth only for simulation purpose. This choice was not done and data were reported as they came out from virtual or physical models. In fact, the aim of this paper is to show the correlation of design parameters among homogeneous families of products. It means that, as long as the error of CFD is repeatable and correlation between parameters assured, new design behaviours can be predicted on the base of old known ones.

The correlation between labyrinth area and its volume is also worth to be further explored. Each single dentate tip causes a pressure drop linked to its geometry. However, considering the labyrinth as a whole, the area on volume ratio takes into account frictional effects on the walls. Increasing this ratio leads to more flow resistance and then a reduction of water discharge.

The correlations which emerged apply to the specific dripper design family. It was noticed how different dripper types show different levels of correlations between parameters. However, among homogenous families, results can be extend to new designs and performance be predicted with a sufficient grade of reliability.

6 CONCLUSIONS AND FUTURE DEVELOPMENTS

This work has presented an approach which was followed to gather data on a specific design problem, the dripper emitters. Numeric simulations were performed on a certain number of meaningful test cases and verified from an experimental point of view. Design parameters were individuated and put in correlation on the base of empirical rules, as in the Design of Experiments methodology.

The aim was to form a knowledge base made of the gathered data and of design rules to help the definition of a new product as new specifications come.

The future development of this work will be the implementation of a knowledge based tool that organizes and manages all these experimental data along with empirical laws. To this aim, all data must be organized into a structured database along with experimental rules that are drawn from data analysis. The system will manage diverse design families and parameters in order to predict the water discharge rate. Possibly, an interaction with a CAD system will be useful to define geometrical layouts.

Finally, in order to widen the knowledge base, all new products must be stored in the data base in order to explicit design information and add new experiments to elaborate stronger parameters correlation rules.

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8 REFERENCES

[1] Mandorli, F., Bordegoni, M., 2000, Product Model Definition Support for Knowledge Aided Engineering Applications Development, Proceedings of ASME-DETC'00, Proceedings CD-ROM.

[2] Cederfeldt, M. Elgh. F., 2005, Design automation in SMEs – current state, potential, need and requirements, Proceedings of ICED 05.

[3] Bermell-Garcìa, P., Fan, I.-S., Li, G., Porter, R., Butter, D., 2001, Effective abstraction of engineering knowledge for KBE implementation, Proceedings of ICED 01, 1:99-106.

[4] Montgomery, D. C., 2001, Design and Analysis of Experiments, 5th ed., John Wiley & Sons Inc., New York.

[5] Wang, W.Z., Liu, Y.Z., Jiang, P.N., Chen, H.P., 2007, Numerical analysis of leakage flow through two labyrinth seals, Journal of Hydrodynamics, 19 (1): 107-112.

[6] Li, Y.K., Yang, P.L., Ren, S.M., Chen, H.P., 2006, Hydraulic characterizations of tortuous flow in path drip irrigation emitter, Journal of Hydrodynamics, 18 (4): 449-457.

[7] Demir, V., Yurdem, H., Degirmencioglu, A., 2007, Development of prediction models for friction losses in drip irrigation laterals equipped with integrated in-line and on-line emitters using dimensional analysis, Biosystems Engineering, 96 (4): 617-631.

[8] Dazhuang, Y., Peiling, Y., Shumei, R., Yunkai, L., 2007, Numerical study on flow property in dentate path of drip emitters, New Zealand Journal of Agricultural Research, 50: 705-712.

[9] Kamrmli, D, 1997, Classification and flow regime analysis of dripper, Journal of Agricultural Engineering Research, 22 (2): 165-173.

[10] Zhang, J., 2007, Numerical and experimental study on hydraulic performance of emitters with arc labyrinth channels, Computers and Electronics in Agriculture 56: 120-129.

[11] McCreary, M.L.., 2007, Tips And Tricks For Using Simulation Doe To Assess The Complex Interactions Of Your Process, Proceedings of Simulation Conference Winter 2007.

[12] Launder, B.E., Spalding, D.B., 1974, The numerical computation of turbulent flow. Comput. Meth. Appl. Mech. 3: 269.

[13] Wei, Q., 2006, Study on hydraulic performance of drip emitters by computational fluid dynamics, Agricultural Water Management '06 – Agriculture Water Management, Ed. Elsevier, 130-136.