تصميم صمام للتحكم في تدفق المياه

Design a Flow Control Valve

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- هندسة ميكانيكية من جامعة بليموث – المملكة المتحدة.
- حاصل على الماجستير من جامعة لندن ساوث بانك – المملكة المتحدة.
- يعمل في الإدارة العامة للطيران المدني.
- محاضر جامعي في الجامعة الدولية – الكويت.
- عضو جمعية المهندسين الكويتية.

ملخص البحث:

يهدف هذا المشروع بشكل أساسي إلى تحسين استهلاك المياه العذبة من خلال استخدام التطبيقات الهندسية المتقدمة. الحل المقدم في هذا المشروع هو استخدام صمام للتحكم في تدفق المياه. ويهدف هذا المشروع إلى تحسين الفوائد البيئية والاقتصادية التي ستؤدي إلى تحقيق مستوى عال من الاستدامة.

تم تطبيق العديد من الدراسات في هذا البحث للوصول للحل الأنسب مثل اجراء مراجعة للأدبيات من أجل دراسة صمام التحكم في تدفق المياه الذي يتضمن العمليات والمكونات والأداء الذي سيوفر فهما كاملا لنقطة تركيز البحث ودراسة جدوى لاستخدام الصمام لغرض التقليل من استهلاك المياه في الزراعة الذكية بهدف تحسين الفوائد الاقتصادية والبيئية التي يمكن تحقيقها من خلال مراجعة الدراسات السابقة وتم أيضا تقديم مجموعة من الافتراضات للنظام من أجل القدرة على محاكاة أداء النظام المصمم من خلال استخدام برنامج الماتلاب.

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Abstract

This project mainly aims to optimize the consumption of freshwater via the usage of advanced engineering applications. The solution presented in this project is using the flow control valve. The aim of this project is planned to improve the environmental and economic benefits which will result in achieving a high level of sustainability. A material selection process was applied to select the most suitable material considered for the flow control valve fabrication. Polyester is estimated to have the highest mechanical performance of the three materials considered because its yield strength is much higher than that of ABS or PLA materials. Polyester is expected to have the highest fracture resistance because its fracture toughness is much higher than that of ABS or PLA materials. On the one hand, ABS density was estimated to achieve the best performance (lowest weight), but its price is the highest, reducing the economic benefits. It was decided that the most appropriate material would be polyester, which provides very high mechanical performance at a low cost and with a low environmental impact. The iteratively solved matlab mathematical model predicted that irrigating 68 farms requires 37 flow control valves while irrigating 207 farms requires only 13 flow control valves. Increasing the number of operation hours is expected to help reduce the number of valves needed for the irrigation process. Furthermore, increasing the amount of water required until the end of the growing season is expected to help shorten the growing season. The number of valves has a significant impact on the flowrate of water. The proposed system can be controlled by an Arduino system, which can be simulated using Tinker CAD software. It is expected that the software used to aid in automatic control of the irrigation system. The control system was designed to be as simple as possible, which helps to reduce the system's initial cost. The soil moisture sensor installed to the control system helped in determining the need of irrigating the farm. As when the moisture is less than 40%, the pumps are energized while in case of the moisture is higher than 40%, then there is no need to irrigate the farm.

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Chapter One: Introduction

1.1. Background

The increase in the demand for water in addition to the limitation of the resources because of the growth of the population as well as the industrial development results in a crisis of water in several countries. In order to reduce this issue, the consumption and the demand management problems are required to be designed in the systems of water distribution. A possible solution that has been presented is the utilization of some specific types of valves in order to reduce water consumption (Tabesh & Hoomehr, 2009).

Most industries have hydraulic transmission systems, one of the key components, in order to control and distribute the flow, is the flow control valve. The flow control valves are widely utilised in several various types depending on the application. However, the typical type has an opening which could be changed for the purpose of decreasing or increasing the rate of the flow. The flow control valve could be manufactured from a variety of materials such as zinc, stainless steel, carbon steel and brass. It provides several choices for a complete and simple system that has the ability to adjust the temperature, pressure and other flow variables. Figure 1-1 represents a schematic diagram for the typical flow control valve (Engineers Post, 2021).

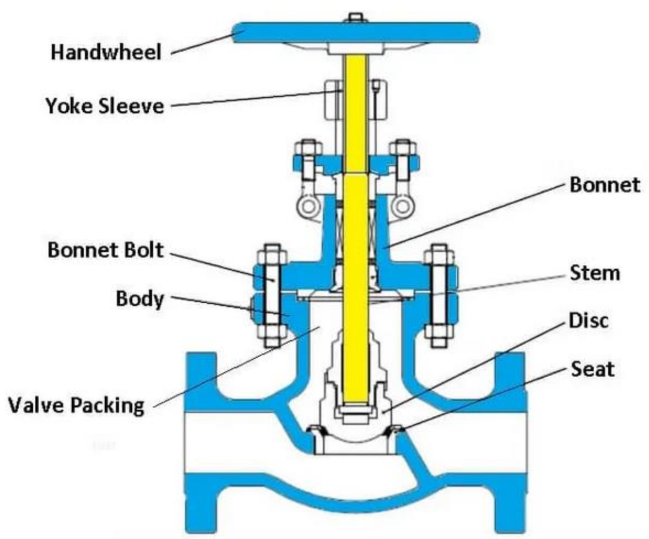

Figure 1-1. A schematic diagram for the typical flow control valve (Engineers Post, 2021).

The components of the flow control valve are represented as follow (Engineers Post, 2021);

- Body

The body is the major part of the valve, as it holds all other parts. It is possible to achieve the piping in the body of the valve with the help of welded joints and bolts. Usually, this part is manufactured from cast iron.

- Bonnet

This part is a cover which is utilised for the body opening and it includes two main parts that are fixed together. The bonnets are used as a cover only in some valves however, it is also possible to use them as valve interior accessories in other types.

- Trim

Usually, this part is presented on the valve inside and it includes the disc, sleeve, seat and stem. It is possible to detect the performance of the valve by the interface of the disc and seat.

- Disc and seat

The main function of the disc is to allow and restrict the flow of the fluid, therefore, it is a circular part of the flow control valve. If the discis closed, the total pressure of the system is implemented to the deck and it is exerted towards the outlet.

- Stem

This part is responsible for the disc connection with the actuator, which fixed the disc in its place. Welded joints in addition to threads are utilised to perform the connection. There are two main types of this part which are rising stem and non-rising stem.

- Actuator

The actuator is one of the major parts of the valve, and it is driven by the assembly of the disc and stem. It is possible to operate the actuators of the control valve manually or by using an electrical motor.

- Handwheel

The handwheel is used to control the closing and opening of the flow control valve manually.

- Valve packing

This par is responsible for preventing the leakage between the bonnet and stem.

1.2. Project Aim

This project mainly aims to optimize the consumption of freshwater via the usage of advanced engineering applications. The solution presented in this project is using the flow control valve. The aim of this project is planned to improve the environmental and economic benefits which will result in achieving a high level of sustainability.

1.3. Project Objectives

It is required to fulfil the following objectives in order to satisfy the main aim of this project;

I. Conducting a literature review in order to study the flow control valve involving the operations, components and performance which will provide a complete understanding of the research focus point.
II. Studying the feasibility of using the flow control valve for the purpose of minimizing the consumption of water in smart farming aiming to improve the economic and environmental benefits which could be achieved by reviewing previous studies.
III. Optimising the flow rate of the water for each area of farming.
IV. Utilising the multi-objective optimization approach in order to obtain the most efficient technology could be utilised in minimizing the water wastage during farming.
V. Present a set of assumptions for the system in order to have the ability to simulate the designed system performance via the usage of MATLAB software.
VI. Using analogic software in order to simulate the water flow of the proposed system.
VII. The results obtained will be analysed and discussed.
VIII. The conclusion will be presented and a group of recommendations will be set for the decision making and future scientific work.

Chapter Two: Literature Review

2.1. Overview

Changing the revolution is the only possible way for adjusting the rate of the flow of a fixed displacement pump, however, there aren't enough technologies for each single power supply in order to vary its revolution effectively. In addition, it is very expensive and complex to obtain the capability of changing the speed. Similarly, it is also expensive to use a variable displacement pump for the purpose of controlling the flow rate speed as these pumps are more expensive than the fixed displacement pumps and they haven't the ability to operate more than one actuator at various speeds. One possible solution is to use flow control valves as they have the ability to effectively control the flow rate, in addition, to operate multiple actuated are various speeds at the same time. The flow control valve has the ability for speed regulation through the orifice aid, and according to the throttling and characteristics of the orifice, the rate of the flow is managed. The advanced valves used throttling only to estimate the flow variation amount. Recently, simulation techniques which are one-dimensional have been common in designing of these types of valves (Coskun, et al., 2016). (Changhai & Hongzhou, 2014) proposed and deduced a seventh-order model in order to study the dynamic response of flow control valve from nonlinear equations depending on the general mechanics, fluid and electromagnetism fundamental law. this study driver the coefficients of the proposed model in terms of the properties of the fluid as well as servo valve physical parameters. an AMESim simulation model depending on existing low-order models and physical laws have been utilised for the purpose of verifying the results of the model presented in this study. it has been found based on the results obtained in this study that the model proposed in this research has the ability to reflect the valve physical behaviour with high accuracy in comparison with the models presented in the literature.

The dynamic behaviour of most of the systems depends on some parameters and components of the system such as the flow control valve. In order to address the dynamic issue resulting from the usage of these components, different architecture of the valves have been developed in various studies, besides, there are available empirical guidelines for the purpose of selecting the best parameters values such as the set pressure in addition to the pilot ratio. However, the characterizing issue of the energy consumption portion results from the usage of these valves, and how the settings of the valve influence this consumption have been addressed in only very few studies according to a systematic approach. (Ritelli & Vacca, 2013) was carried out in order to address this problem in addition to presenting a general approach for the purpose of evaluating the consumption of the energy results from these valves for a given operating machine cycle where they are being utilised. Particularly, in order to study the influence of the valves in the systems, this study used a graphical method. This study also utilised this approach for potentials interpretation of the recovery of energy according to various settings of the valve. The results obtained in this paper have been validated by experimental results which provide to study of the effect of the valves on the system dynamic behaviour besides studying their energy consumption.

2.2. Operation of Flow Control Valve

It is possible to control the flow of the fluid in the flow control valve by varying the area that the fluid passes through it. When controlling the flow of the fluid, a pressure drop occurs, so that, it is required to take this drop into consideration when selecting the flow control valve type and depending on the application. In the typical circuit hydraulic, there is a fluctuation of the pressure at the load as it is sometimes lower and sometimes higher, however, the pressure at the inlet is constant. That is because the fluid is pumped with constant pressure but this pressure may vary at the outlet. There is two possible way in order to overcome this problem, either through using pressure-compensated pumps or a pressure compensated flow control valve as the valve has the ability to keep a constant flow rate even with the variation of the load.

2.2.1. Fundamental of Flow Control Valve

It is possible to achieve the regulation of the flow in the valve through resistance variation as the valve is stroked. That is mean that when there is a change in the cross-sectional area. When there is a movement of the fluid into the smaller diameter of the valve orifice from the pipeline, there is an increase in the velocity to allow the flow of the mass via the valve. The required energy to increase the fluid flow velocity comes at the pressure expense, the lowest pressure point is at the highest pressure point which is the point where the smallest cross-section area of the valve. This point is called “vena contracta”. In order to illustrate the low behaviour via the valve, a simplified orifice of the valve with a pipeline is represented in the following figure (Bhatia, 2020).

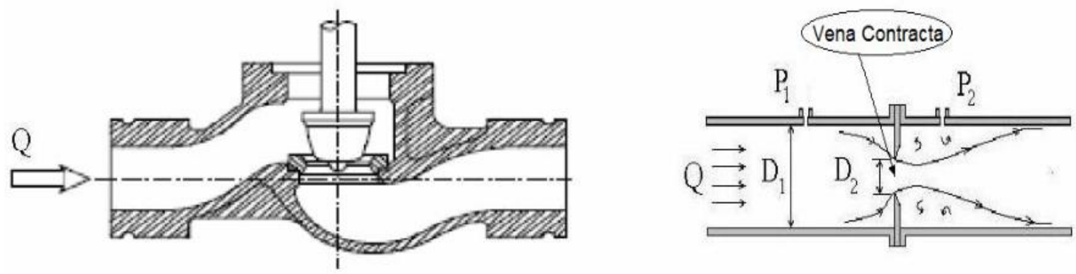

Figure 2-1. A simplified orifice of the valve with a pipeline (Bhatia, 2020).

When the fluid passes the point that has the smallest cross-section area, the pressure becomes at its minimum value and the maximum velocity is obtained. Hence, it is expected that the largest velocity at the valve is internal on the downstream and upper stream. After the fluid passes this point, there is a decrease in the velocity of the fluid with the increase in the diameter of the pipe, which allows for some recovery of the pressure. It is very required to understand the change in the velocity and pressure when the flow passes through the valve. The continuity equation is the best to describe this phenomenon (Bhatia, 2020).

$$V1 * A1 = V2 * A2$$

Where;

• A = flow area, and V = mean velocity.

• Upstream circumstances are referred to by subscript 1.

• downstream circumstances are referred to by subscript 2.

- **Control Valve Capacity – Cv**

In order to determine the size of the control valve, it is required to know the flow amount that could be obtained via the valve for any situation of the valve in terms of opening as well as for any given differential of the pressure. Flow coefficient (cv) could be defined as the relationship between the flow rate and the pressure drop. And also, it could be defined as the gallons per minute at 60°f to go through a valve, which is fully open, at 1 psi of pressure drop (Bhatia, 2020).

- **Flashing**

As mentioned before, at the point where there is the maximum velocity, there is minimum pressure. By assuming incompressible fluid passes through the valve, if the vapour pressure of the liquid is higher than the pressure of the fluid flow, as the pressure downstream rises, vapour bubbles develop inside the valve and collapse into themselves. This causes tremendous shock waves that are extremely loud and will almost definitely destroy the apparatus (Bhatia, 2020).

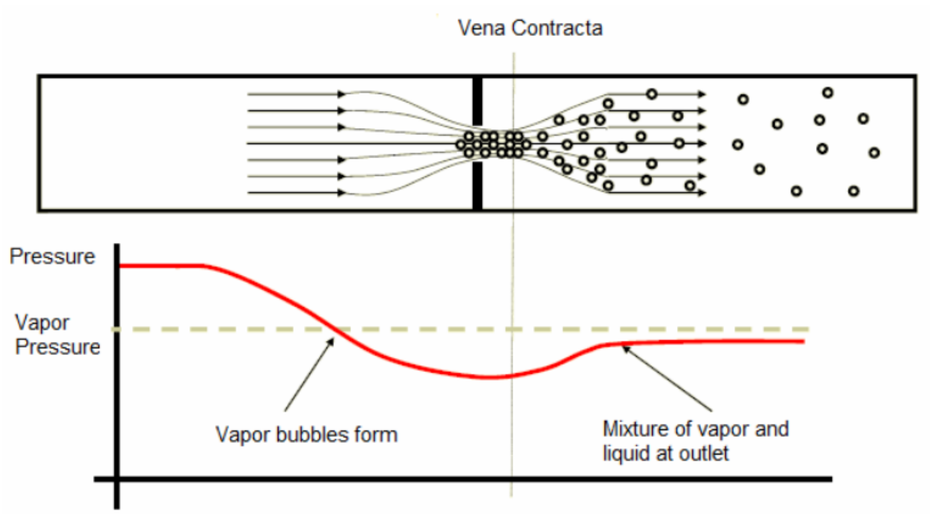

Figure 2-2. Flashing (Bhatia, 2020).

The flashing effect negatively on the valve as there may be damage in the materials associated with the formation of the sand-blasted surface. And the flashing may lead to reduce the efficiency of the valve.

- **Cavitation**

There is a similarity between the flashing and the cavitation as liquid vaporize into vapour bubbles when its liquid pressure falls below its vapour pressure (Bhatia, 2020).

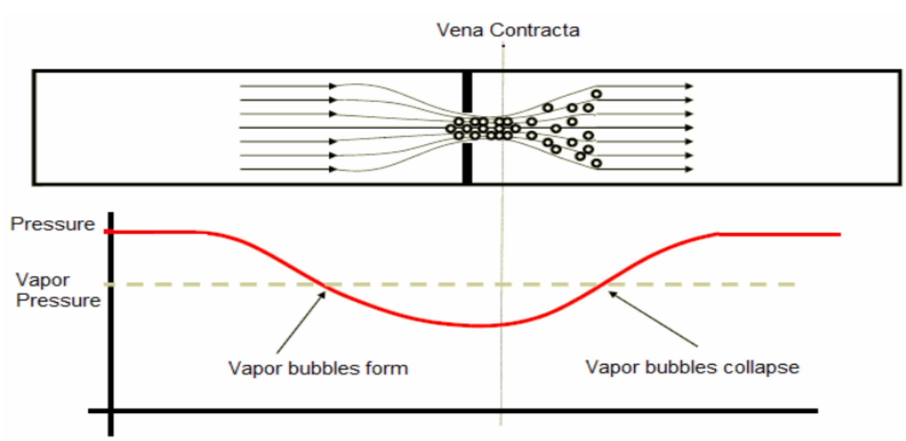

Figure 2-3. Cavitation of flow control valve (Bhatia, 2020)..

The difference between the flashing and cavitation is that in the phenomenon of cavitation, there is an increase in the pressure of the liquid over the vapour pressure during the recovery of the pressure and turns back into the liquid phase. However, in the flashing, the pressure of the liquid remains below the vapour pressure (Bhatia, 2020).

Several studies investigated and evaluated the phenomenon of cavitation. (Zheng & Wang, 2019) carried out an experimental investigation on the flow structure of the cavitation in flow control valve at various openings. in order to determine the characteristics of the flow of the cavitation, the visualization test as well as the model valve have been conducted. The cavitation occurs at the seat of the valve and on the top of the spool of the valve.

The cavitation that occurs in the flow control valve results in damaging the system of the piping besides increasing the waste of energy. (Jin, et al., 2020) used a cavitation model in order to minimise the cavitation inside the flow control valve through the investigation of the influence of various core shapes of the valve involving circular truncated cone, flat bottom, ellipsoid and cylinder. The distribution of vapour volume fraction, velocity and pressure were obtained. After that, there was a comparison between the obtained results with various core shapes of the valve and various displacements of the valve core. There was also forecasting and comparison for the total vapour volumes. It has been found based on the obtained results that primarily, the vapour occurs between the surface of the valve core and the sleeve. The intensity of cavitation of the valves with cylinder and ellipsoid shape is the greatest. There is an increase in the total vapour volumes with the increase of the displacement of the valve core, however, it decreases after that.

(Zhang , et al., 2190) used a multiphase cavitation model for the purpose of investigating the characteristics of the cavitation as well as the drop in the pressure in the following control valve of sleeve type for various pressure differences and different displacement of the core. It has been found that the increase in the difference the pressure results in more serious cavitation. The intensity of the cavitation is influenced slightly by the pressure difference. With the decrease in the displacement of the core of the valve, there is an enhancement of the influence of the difference of the pressure on the intensity of cavitation.

2.3. Applications of flow control valve

One of the main functions of the flow control valve is controlling the piston speed based on the area of the piston and flow rate.

$$V = Q/A$$

Where V represents the speed of the piston, Q represents the flow rate and A represents that area of the piston.

Another function is controlling the flow rate for the purpose of regulating the power to the sub-circuits

$$H = Q * P$$

Where H represents the hydraulic power, Q represents the flow rate and P represents the pressure (Mustansiriyah University, 2020).

2.4. Flow control valve classification

It is possible to classify the flow control valve into two categories which are Non-Pressure-Compensated and Pressure-Compensated (Mustansiriyah University, 2020).

- **Non-Pressure-Compensated flow control valve**

This type is utilised when the pressure of the system is almost constant and it is not critical to consider the motoring speeds. The principals of operation of this type of valve are that the flow remains constant via the orifice if the drop of the pressure remains the same across it. This means that the flow rate via the orifice relates to the drop of the pressure across it. There are some disadvantages of this type which are represented as follows. The pressure at the inlet is the pressure provided by the pump so, it is possible to keep this pressure constant. Therefore, the occurrence of the pressure variations is at the outlet. This indicates that the rate of the flow depends significantly on the workload. Therefore, it is not possible to define the speed of the piston accurately through the usage of this type of the valve when there is a variation in the workload (Mustansiriyah University, 2020).

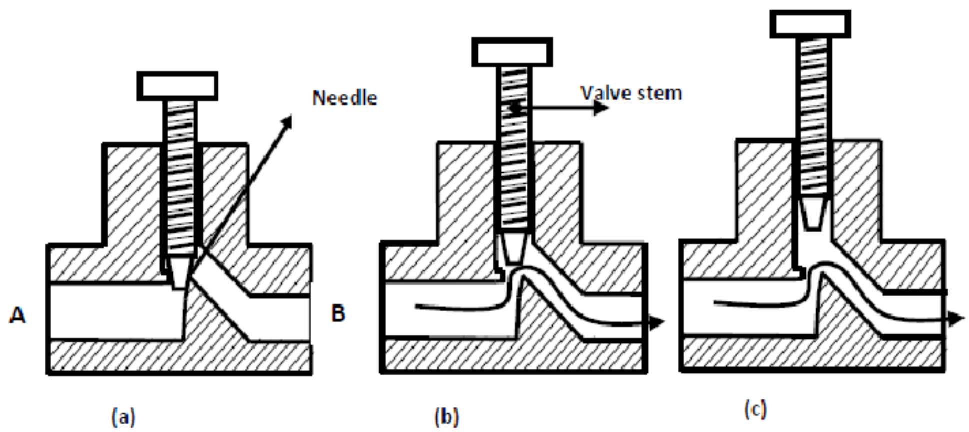

Figure 2-4. Non-pressure compensated flow control valve schematic diagram where a) fully closed, b) partially open and c) fully open (Mustansiriyah University, 2020).

- **Pressure-Compensated flow control valve**

In this type of flow control valve, the office size could be changed in relation to the variation in the pressure of the system therefore, it overcomes the issue that the non-compensated pressure flow valve couldn't solve. It is possible to achieve this through the usage of a spring-loaded compensator spool which decreases the orifice size when there is an increase in the pressure drop. Once setting the valve, the compensator of the pressure works in order to keep the drop-in pressure nearly constant. It operates based on a mechanism of feedback from the pressure at the outlet. This leads to maintaining a constant flow rate via the orifice. A schematic diagram of this type is presented in Figure 2-5. This type consists of the compensator spool as well as the main pool. The main position of the spool is controlled by the adjustment knob which adjusted the size of the orifice at the outlet. The pilot is used to deliver the upstream pressure to the valve. The spool is biased by the compensator spring so that it becomes fully open, if there is an increase in the drop of the pressure, there will be also relative increase in the upstream pressure, and there will be a movement to the compensator spool against the spring force to the right. This will lead to a reduction in the flow therefore the drop of the pressure will be reduced and tries to reach an equilibrium position as long as there is a constant flow (Mustansiriyah University, 2020).

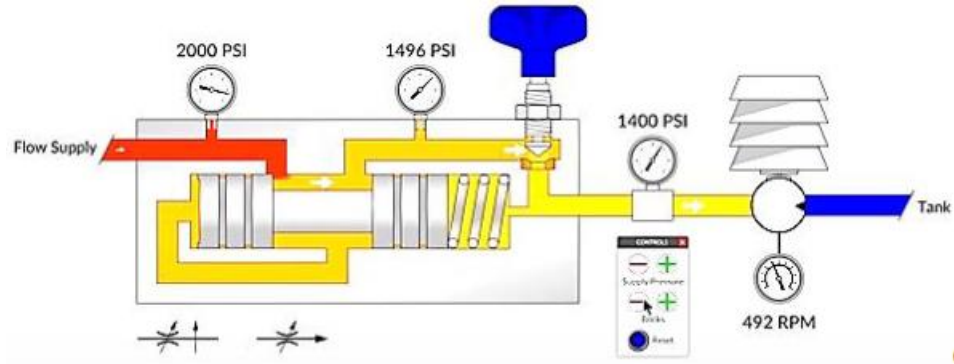

Figure 2-5. Pressure-Compensated flow control valve at full load (Mustansiriyah University, 2020).

2.5. Types of flow control valve

2.5.1. Ball Valves

These valves are shutoff valves where a ball is utilised to start and stop the fluid flow downstream of the valve. The ball in this type of valve has the same function as the disc in other types. Once turning the handle of the valve in order to open it, there is a rotation for the ball where the entire hole part is machined via the ball is in line with the outlet and inlet of the body of the valve which allows the flow of the fluid through the valve. The flow stops when there is a rotation of the ball so that the path of the flow is perpendicular to the hole. Most of the valves of the ball type are quick-acting. A 90-degree turn of the lever is required to be either completely closed or fully open. This characteristic, in addition to the generated turbulent flow when the valve is partially opened, limits the utilisation of this type of valve as a device that controls the flow. Generally, this type is used to open and close the fluid path (Mobley, , 2000).

2.5.2. Gate Valves

This type is usually utilised when minimum flow restrictions and a straight-line flow are required. A sliding plate is utilised in gate valves inside the body of the valve in order to pre-limit, limit or stop the fluid flow. The shape of the gate is usually a wedge. When the valve is completely open, there is a full drawing of the gate to the bonnet of the valve. Therefore, no restrictions on the flow and thus the flow passes via the completely open valve. This results in that there is little or no drop in the pressure or restriction of the flow via the valve. For throttling volume, this type of valve isn't suitable. There is a difficulty in flow control as the design of the valve as the fluid flow slapping against the gate, which is partially opened, may lead to damage to the valve. It is possible to classify these types of valves as non-rising-stem valves or as rising-stem valves. Figure 2-6 represents the non- rising-stem type. Into the gate, the stem is threaded. As there is a rotation in the stem handwheel, the gate moves down or up the stem while the stem remains in its position. For the purpose of indicating the gate position, this type has a pointer indicator threaded onto the stem's upper end. The rising stems valve are presented in Figure 2-6. This type of valves when is required to determine the situation of the valve through immediate inspection (Mobley, , 2000).

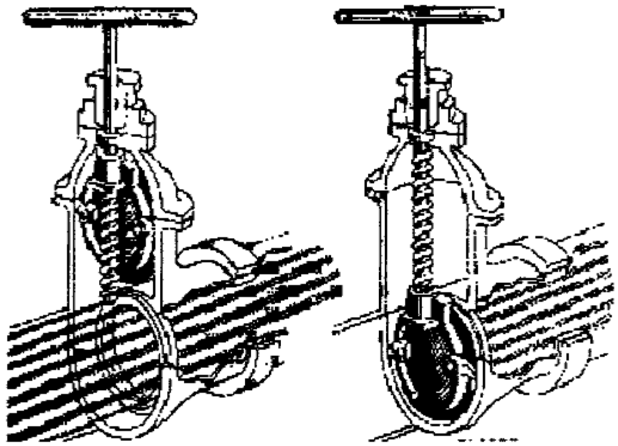

Figure 2-6. Non-rising-stem valves (Mobley, , 2000).

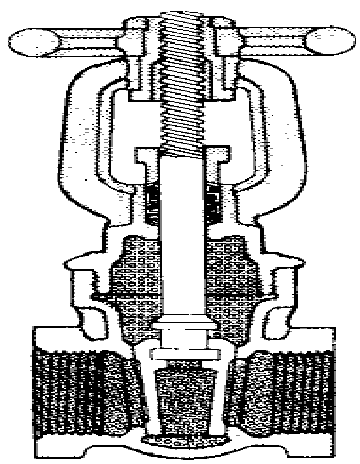

Figure 2-7. Rising stems valve (Mobley, , 2000).

This is the most common type among all flow control valves. The name of this valve comes from the valve body's globular shape. The opening and the outlet of this valve are arranged in a way so that it is possible to achieve the requirements of the flow. Cross-flow, angle and straight flow valves are shown in Figure 2-7. The disc the part in this type of the valve that controls the flow of the fluid and this disc is connected to the stem of the valve. The valve is closed when turning in the stem of the valve until the disc seated into the seat of the valve. This leads to prevent the flow of the fluid via the valve. The machining of the edge of the seat and the disc is performed with very high accuracy, therefore, a tight seal is formed when closing the valve. The fluid passes between the edge of the seat and the edge of the disc when the valve is opened. No unbalanced pressure is applied to the disc as the flow of the fluid is equal on all support centre sides when the valve is open. Therefore, uneven wear is caused. The disc position in relation to the seat of the valve regulates the flow of the fluid that passes within the valve. It is possible to use this valve as a throttling besides it is a function to stop or path the flow when it is completely closed or fully open. However, as the area of the surface of the seating is large, this valve is not applicable when one adjustment is needed. It is not recommended to jammed this type in the position of the open (Mobley, , 2000).

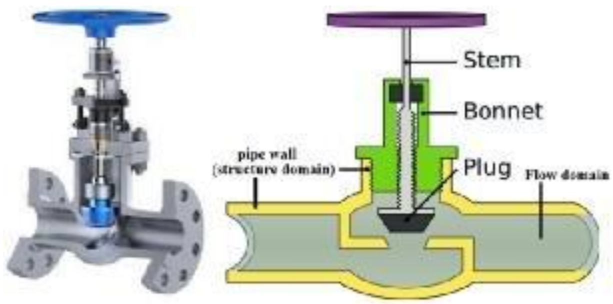

Figure 2-8. Globe valve (Hussein, 2017).

2.5.3. Needle Valves

The operation of the needle valve is similar to the globe valve operations. A long-tapered point exists instead of the disc.

2.6. Valve performance

The total ability to solve the technical problem being addressed, i.e. Water wastage, is used to evaluate the performance of control valves. Control valves are an important part of the system that connects the operation of computers and sensors. Control valves are the hardware objects that supply the control system's intended outputs. Control valves' physical performance is typically reinforced via the vast majority of the research papers evaluated since there are several instances of positive reinforcement that emphasise the effectiveness of these valves in smart farming (Mohan, et al., 2021).

2.6.1. Enhance Valve Performance

- **Fault Detection**

There is a significant role for the flow control valve in the efficient and stable operation of the loop of control of any process, the process of the fluid low, there are many reasons that may lead to increase the possibility of failure occurrence inflow control valves such as ageing, mechanical issues of the valve, different properties of the flowing liquid via the pipa and high inlet pressure. The control loop could be significantly enhanced via the usage of a technique that has the ability to estimate the faults in the valve. (Venkata & Rao, 2019) developed a method for the purpose of estimating the failure in the flow control valve which could be achieved by analysing the data of vibration at the valve outlet. The diagnosis of the failure of the valve is performed through the analysis of the variation of the pipe vibration because of the change in the pattern of the flow induced by the valve. The considered failures were insufficient and inflow supply pressure faults. Signal processing technique was utilised in order to process the obtained data of vibration such as Fourier transform or amplification. In order to classify the data of the vibration into two categories, the algorithm of support vector machine (SVM) has been utilised, one faulty and the other normal. This study trained that designed algorithm in order to identify faults and subjected these faults to a practical setup to test. An accuracy of 97%. Has been obtained from the results of the test.

(Farzaneh-Gord & Khoshnazar, 2016) was carried out in order to develop a zero-dimensional numerical approach depending on the angle of the crank aiming to study reciprocating natural gas compressors with failures of the valve. The model presented in this study considered the movement of the piston, the dynamic of the valve, the mass flow rate and the equations of the orifice. To this end, this study investigated three volumes of control involving energy equations, discharge chambers and compressor cylinders. There may be a leakage in the valve due to the failures of the valve involving springs deterioration, wearing on seat and plate and failure in valve plate. For the simulation of the leakage of the valve, a hole in the plate of the valve has been taken into consideration. For normal operations of the compressor with a non-fault valve, there was a validation for the results obtained in this study with the results obtained in previous studies. It has been found based on the forecasted results that the discharge and suction valve failures reduce the mass flow rate of the compressor in addition to increasing the discharge temperature of the gas. Moreover, the influence of the failure of the suction valve is more critical than the failure of the discharge valve. Besides, it’s possible to detect the fault of the valve by monitoring the fluid temperature of the discharge and suction chambers.

- **Enhance Efficiency**

Significant power is generated by hydraulic systems used in industries, construction and farming. Generally, because the hydraulic supply is constant, there is a low efficiency for the traditional processes of the hydraulic system where variable power is required. In addition, some losses are caused in the components of the system such as valves besides the losses of overflowing and throttling. This all leads to reduced efficiency of the hydraulic system (Wrat, et al., 2020). (Domagała, et al., 2019) presented a numerical simulation for the fluid flow within the flow control valve through the usage of Computational fluid dynamic (CFD). the simulation of the flow of the fluid provides an investigation of the phenomena which occur during the flow of the fluid which could be utilised during the process of the design in order to reduce the energy consumed by the valve.

2.7. Related studies

(Gorev, et al., 2016) Investigated that the Flow control valves (FCVS) with a non-zero loss coefficient may be unrealistically predicted by a commercial products water distribution network modelling programme. This approach models an FCV with a nonzero loss coefficient K as a composite connection consisting of an FCV with the same setting but a 0-loss coefficient and a synthetic pipe with an insignificantly tiny major loss and a minor loss coefficient equivalent to K. No modifications to the computer's hydraulic solver are required to apply the suggested method. It is common in water distribution systems to utilize control valves in order to manipulate flow and pressure. In spite of this, most hydraulic simulators, such as the industry standard EPANET 2 version 2.00.12, struggle to simulate its behaviour. Assumptions about the valve condition are made at the start of the iterative process, verified in between iterations, and any required adjustments are made using heuristics in EPANET 2 version 2.00.12. Hydraulic modelling experts have come to recognize the EPANET 2 version 2.00.12 approach as a useful tool in practice, although there are certain cases when EPANET 2 version 2.00.12 fails to provide an answer or gives inaccurate findings. There have been new ways to model control valves in recent years. In other words, it may be stated as the reduction of material or content functions based on additional constraints. In other words, control valves are addressed in a nodal or loop formulation. Because EPANET 2 version 2.0.12 relies on a hybrid node-loop formulation for its global gradient algorithm (GGA), these approaches cannot be implemented.

(Alvarruiz, et al., 2018) Proposed an improved methodology to modelling pressure and flow-regulating mechanisms. EPANET's global gradient technique is quite similar to the iterations pr oduced by the approach the researchers have described since it makes use of a symmetric matrix for the underlying linear systems, making it easier to construct and more efficient to solve the pr oblem. Hydrological modelling of the behaviour of water distribution systems (wdss) is currently considered essential for decision-making in both the context of planning and in the course of daily operations of a WDS. To effectively address challenges like leakage, water management, investment management, and endurance, it is necessary to model networks at ever finer levels of detail. These models are built with the assistance of geographic information systems, which are usually found in most utilities because they supply all of the information on the resources that comprise a network. Although the models may be manipulated and run by hand, the availability of ever faster and more effective simulation algorithms is required in order to perform appropriate tasks in which modelling is the computational kernel.

(Piller & Van Zyl, 2014) Investigated Control valves are often employed in water distribution systems, for example. A detailed grasp of the operational states of the device or a computationally intensive search for all possible operating states is often necessary before beginning modelling work on these devices. Flow control, pressure maintaining, pressure reducing, and check valves, formerly difficult to simulate using conventional methodologies, may now be included in long-term water distribution system simulations. Instead of utilising the standard discrete control problem formulation, the Karush-Kuhn-Tucker equations may be used to solve an optimization problem with constraints. When solving an optimization problem with constraints, the Karush-

Kuhn-Tucker equations may be utilised as an alternative to the classic discrete control problem formulation. The recommended method saves time by eliminating the requirement to assess each valve's operation on an individual basis (open, closed, or active). Control valves are employed to reduce deviations from objectives, and a restricted least squares problem is utilised to solve this issue. The following sections of this paper address the first strategy in further detail. The control variables (valve settings) are updated using Levenberg-Marquardt iterations, which are based on the state equations. For the control variables, state equations may be utilised to construct sensitivity equations, which can then be used to calculate their values (valve settings). In order to show that the technique can be used in many different situations, results from basic topics and case studies

are presented.

(Kepa, 2021) The purpose of this investigation is to analyse the water distribution performance of a system. The water distribution system is being scrutinised for 6 small towns. This is precisely the time people reside in rural regions covered by the water supply network, which covers an area of around 50 square kilometres (2020). The region's notable elevation changes are due in large part to this. For the greater part of water-pipe network users: homes, public buildings, recreational areas, service and craft businesses, religious institutions, commercial and agricultural enterprises, and breeding farms, an in-network deep well and water recycling tank supply the network with water. The research was conducted with the use of a hydraulic model. The model was developed using mathematical and practical information recorded by the Epanet application. Because it had been tested with a subset of data, the model was validated. This analysis also included a number of computational methods to illustrate how the network would behave in the case of fluctuating water quality and quantity. A single-period strategy was applied because of the nature of the data. Using the model we constructed, we were able to determine the pressure difference and flow rates of the operating parameters at different locations in the network. A recent analysis has shown that the network's current performance is subpar. When prices increase, water pressure might be high in certain parts of the network, but water is still delivered to all consumers. In times of heavy demand, the reservoir, which supplies much of the water distribution network, has a restricted supply of water and the pumping mechanism cannot compensate for this.

(Mehta, et al., 2015) Investigated that there is an increasing need for municipal water services, such as water delivery for household use, irrigation, and so on. Finding and protecting the water supply is critical, and it must be exploited to its utmost potential. Water is in short supply, despite the fact that demand is rising across a broad variety of sectors and activities. As a result, governments throughout the globe are scrambling to meet rising water demands while also dealing with dwindling supplies. A new water distribution system or an upgrade to an existing one will be necessary to address this issue. It's possible to handle these kinds of problems using a variety of technologies, including LOOP, mikenets, stanets, epanets, and WATERGEMS. There were water shortages and high pressure in several parts of Surat City, which made life tough for many people. The Punagam Region in Surat City was chosen because of this. Hydraulic software EPANET is being used by researchers as part of their analysis to model the current water distribution network and uncover any opportunities for development in the network's construction and optimization in order to better serve their users in terms of water quality and volume. The state's Punagam region is home to five esrs (Elevated Storage Reservoirs). Hydraulic parameters such as head, pressure, flow rate, hydraulic gradient, and head loss have been simulated using a computer model. The EPANET technology was used to construct the village's water distribution system after performing simulations against real data. Researchers want to see whether there are any vulnerabilities in the current water distribution system, so we're doing an investigation to find out if there are any. All places in the investigation were determined to have sufficient water pressures and flow rates, as well as high enough velocities. This study's conclusions suggest that lower pipe diameters be swapped out for bigger ones. It is recommended that the discharge in that area be increased as well, in order to meet the current demand.

Chapter Three: Methodology

3.1. Overview

It has been planned to achieve the proposed study by following a set of scientific approaches which are presented in the following flowchart.

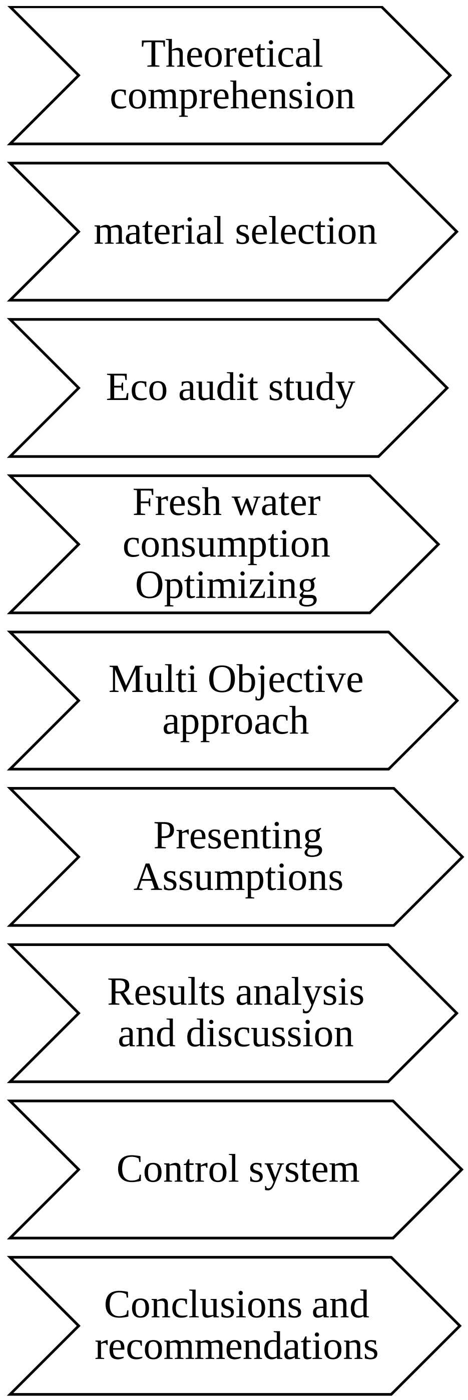

Figure 3-1. Research methodology

3.2. Theoretical Comprehension

The theoretical comprehension of this project is very important to achieve the main aim. The major goal of the proposed research is to use current engineering techniques and technology to reduce water consumption while also making farming smarter. It has been planned to carry out a literature review regarding the flow control valve by taking into consideration its operations, components as well as performance for the purpose of providing important knowledge about the focal point of this project. In addition, reviewing studies on the feasibility of using these valves in agricultural systems (smart farming) to reduce the consumption of the water will lead to a significant enhancement in the environmental and economic benefits. The later specified emphasis on a theoretical comprehension of this study focal point will assist the researcher in following such a scientific technique that produces a high level of accuracy. Readers, on the other hand, may comprehend and relate to the point of the view of the project.

The main objective of this study is to achieve such an intelligent farming system that achieves the highest efficiency by reducing the water consumption as well as increasing the farming area as possible as it could be. Comparing with the farming in Europe, the farming in Kuwait is estimated to consume much higher amount of water for the same farming area due to the weather conditions difference between Kuwait and Europe. Kuwait is characterized by its hot and dry climate that is estimated to result in a noticeable increase in the water consumed in farming such an area comparing with Europe that is characterized by cold and wet climate.

3.3. Material selection process

The main objective of the proposed material selection process is to select the most suitable material that achieves the highest performance with high economic and environmental benefits. This was planned to be achieved using CES software package, which includes a huge database of the available materials in the globe. Aiming to satisfy the latter mentioned objective, a performance index equation was formulated by considering the properties that required to maximized and minimized. The following table presents these properties;

Objective	Property	Unit
To maximize	Yield Strength	MPa
	Fracture toughness	MPa
	Fatigue strength	$Pa.m^{0.5}$
To minimize	Density	Kg/m^3
	Price	GBP/Kg
	CO_2 footprint	$Kg_{CO2}/Kg_{material}$
	Energy consumption	$KJ/Kg_{material}$

Consequently, the performance index can be formulated as it is shown in the following equation;

$$PI = \frac{Yield\ strength * fracture\ toughness * fatigue\ strength}{\rho * price * CO2\ footpring * energy\ consumption}$$

The performance index equation was plotted against the price of the plastic materials as it is shown in the following figure. The decision was taken to consider three different materials, which are;

1. Polyester/E-glass fiber, pultruded composite rod, unidirectional laminate
2. ABS+PA (unfilled)
3. PLA (30% mineral, impact-modified)

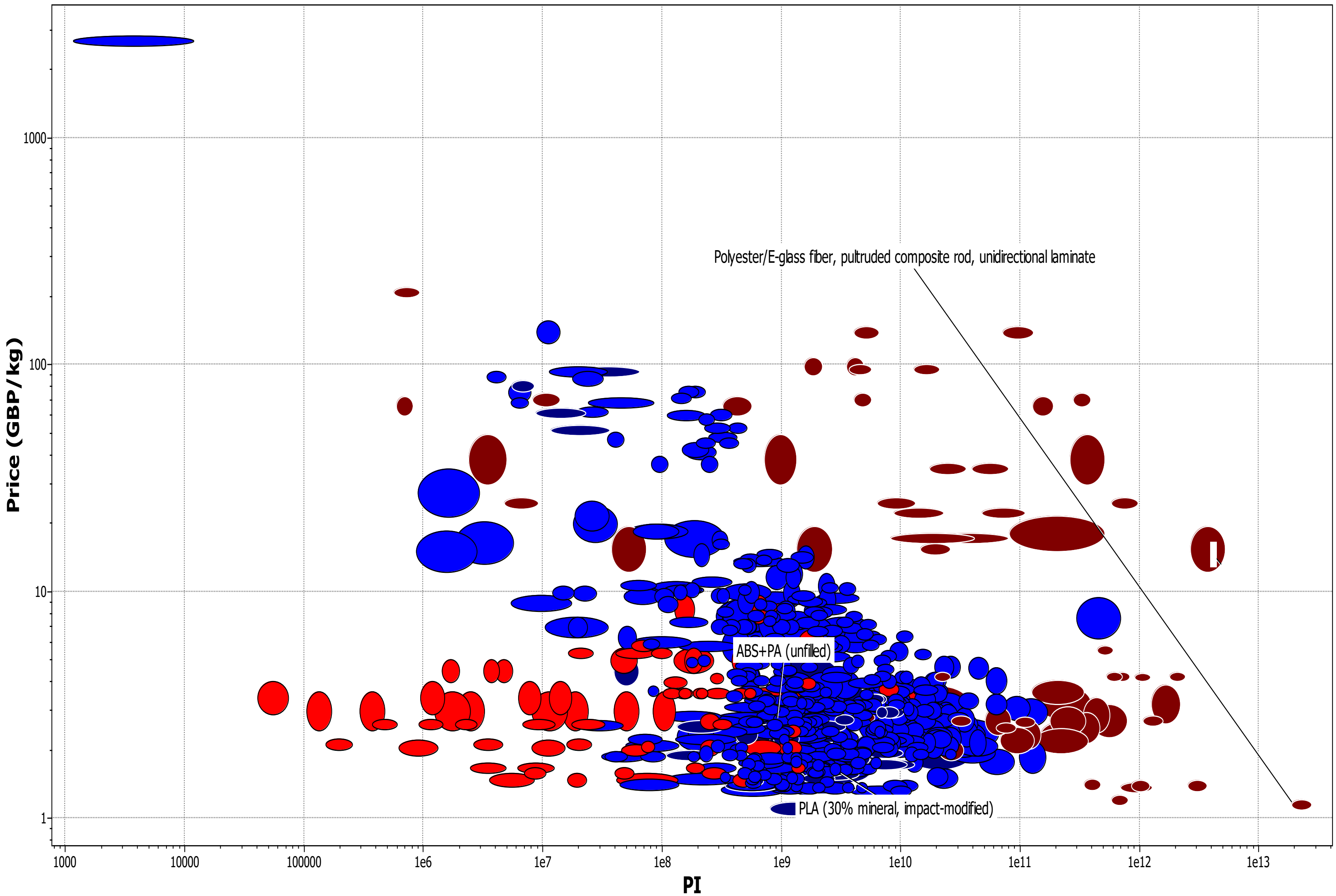

Figure 3-2.The relationship between the material price and performance index using CES software package.

3.4. Eco audit study

Regarding the three materials had been considered using CES material selection package, the decision was taken to 3D model a flow control valve using Solidworks software package. Figure 3.3 presents the 3D model of the flow control valve had been considered in the proposed Eco Audit study.

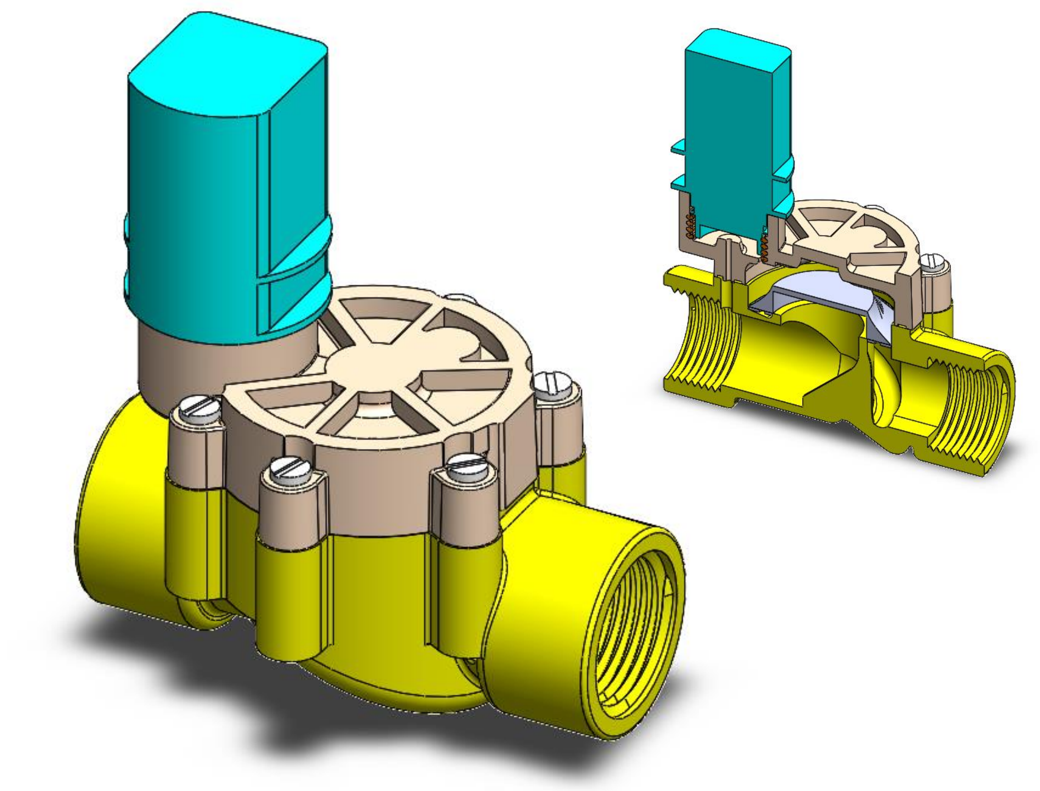

Figure 3-3. A 3D model of the flow control valve had been considered in the proposed Eco Audit study.

The 3D modelled flow control valve mainly consists of such constructing parts that are described as follows;

The main body of the valve which is presented in figure 3.4, the body of the valve which shown in figure 3.5, the spring that is shown in figure 3.6, filter which is shown in figure 3.7, diaphragm that is presented in figure 3.8 and the solenoid (electronic and control part) that is shown in figure 3.9 as a black box.

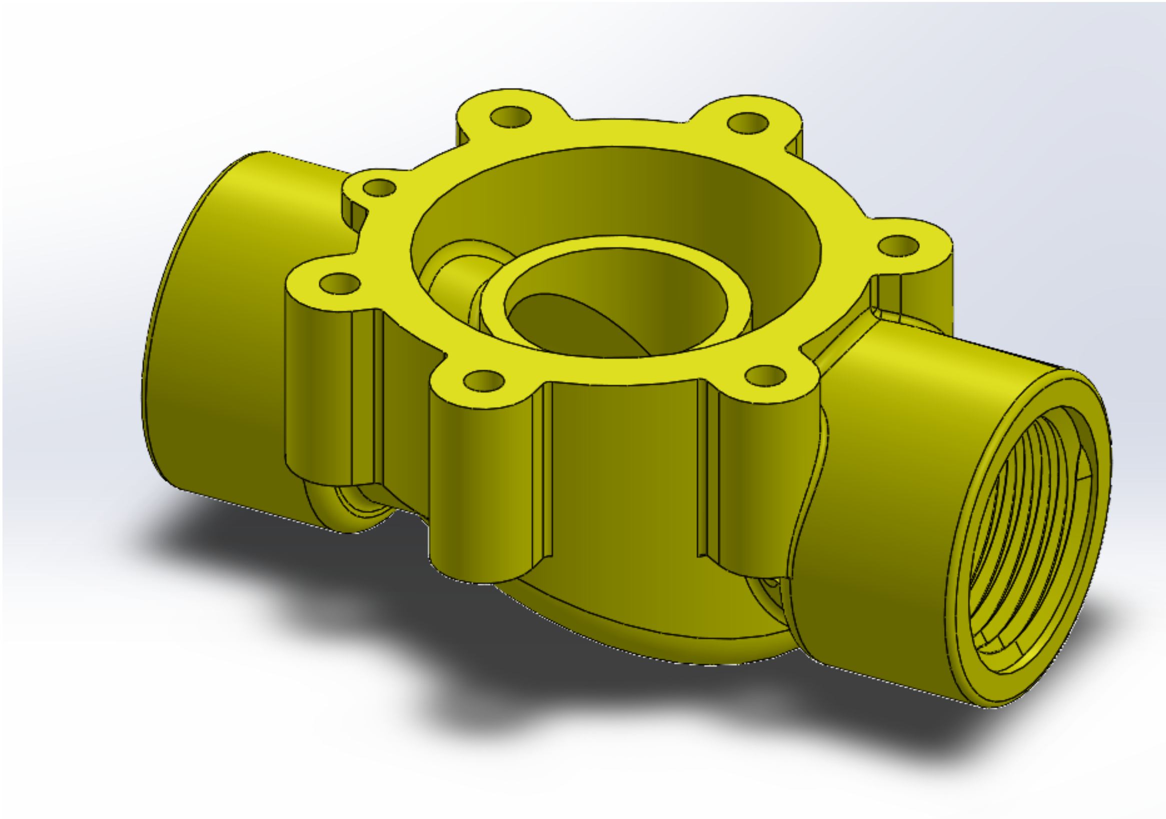

Figure 3-4. 3D model for the main body of the flow control valve.

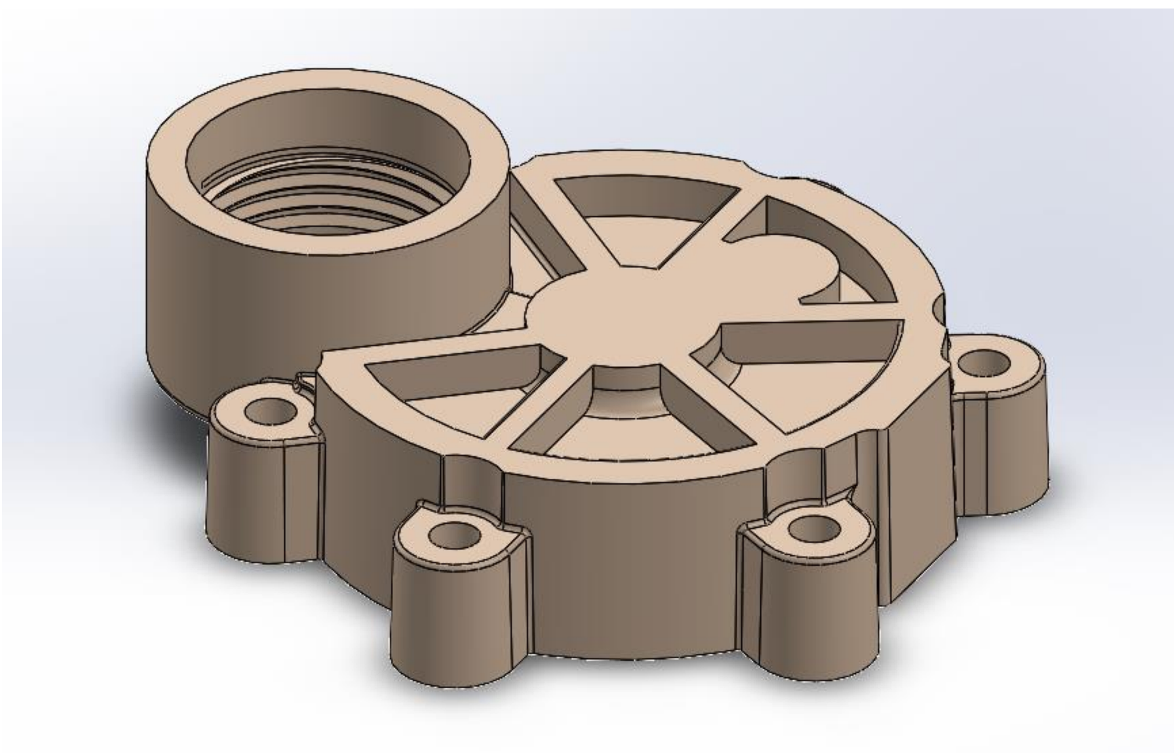

Figure 3-5. 3D model for the body of the flow control valve.

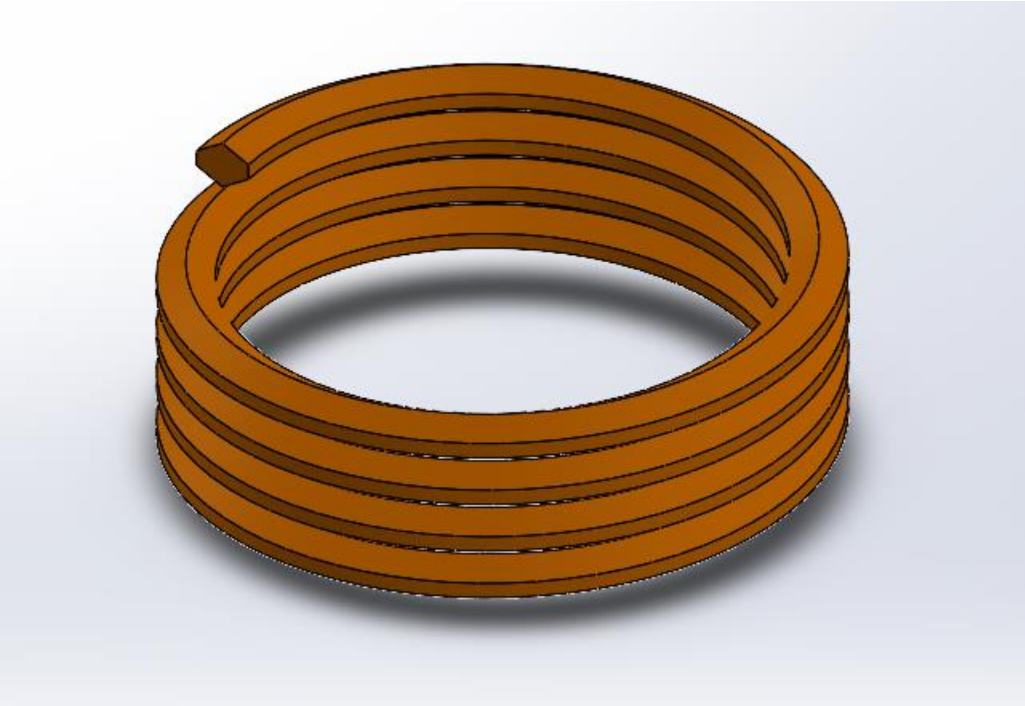

Figure 3-6. 3D model for the spring of the flow control valve.

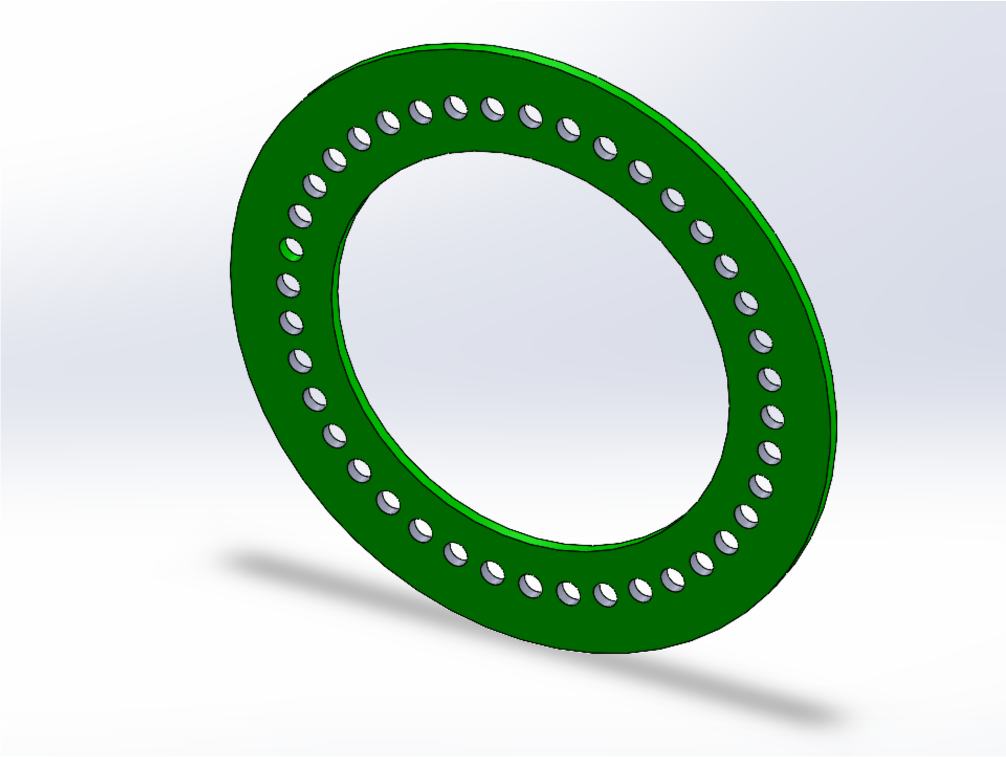

Figure 3-7. 3D model for the filter of the flow control valve.

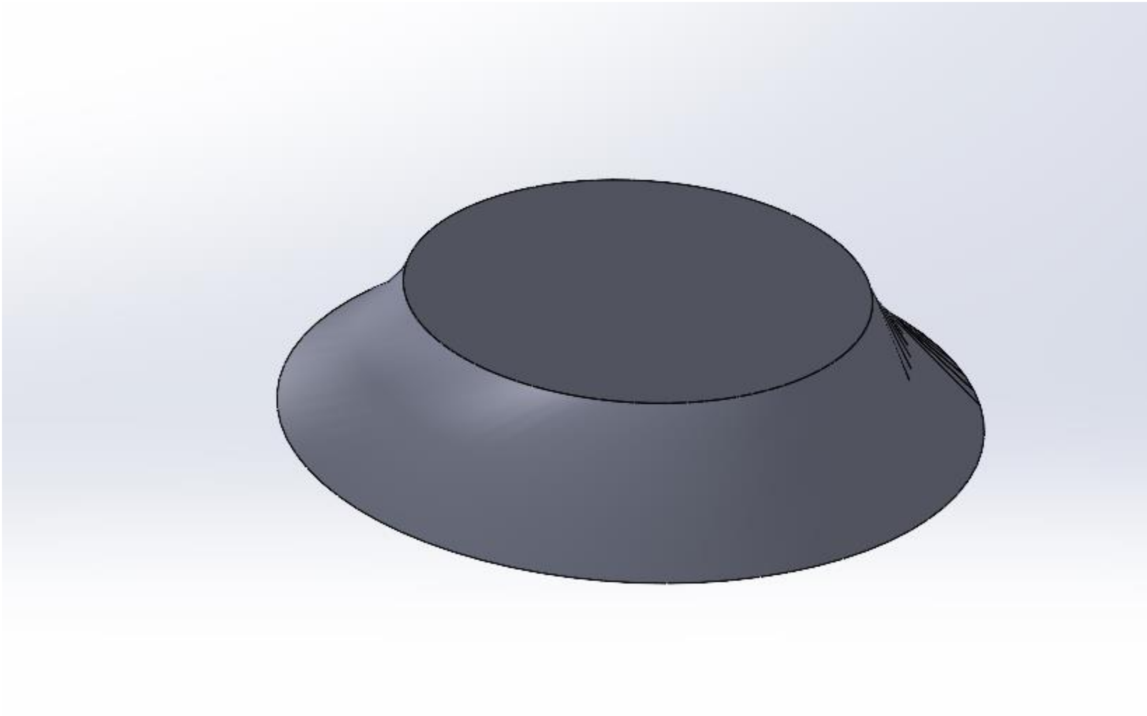

Figure 3-8. 3D model for the diaphragm of the flow control valve.

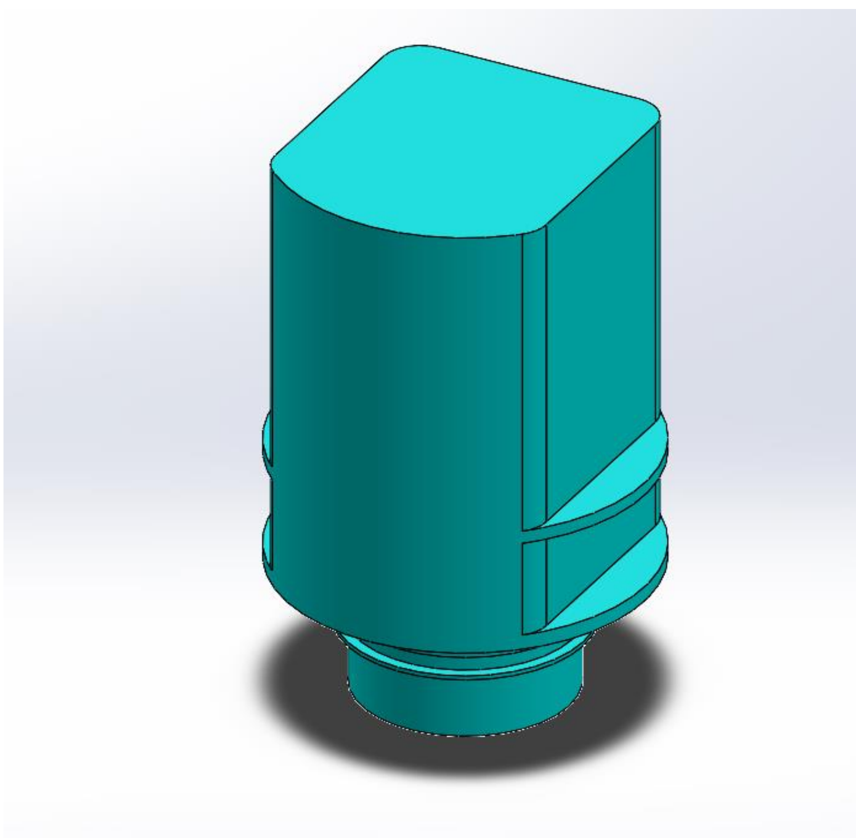

Figure 3-9. 3D model for the solenoid of the flow control valve.

According to the decisions were taken regarding the material should be considered in this study, their properties are identified according to database of CES and attached in Appendices section. A sustainability study were decided to be applied using Solidworks software. The decision was taken to consider Polyester/E-glass fiber as being the base material that the other two materials (ABS and PLA) would be compared with.

The eco audit study would be applied using Solidworks should be based on a group of assumptions that are presented as follows;

- All parts in the 3D modelled flow control valve are made from the same material.
- The flow control valve is manufactured in Asia, which helps in estimating the environmental negative circumstances resulted due to the shipping for such a location to another. The utilization of the flow control valve was decided to be in Europe with a shipping distance (on ships) 16093 km.
- The flow control valve was decided to be manufactured to operate for five years.
- The manufacturing process considered to fabricate the flow control valve is injection molded.
- The flow control valve was planned to be painted using a solvent-based paint.

3.5. Fresh Water Consumption Optimisation

As being the focal point of this project, it has been decided that the freshwater consumption optimisation will be performed through the usage of a flow control valve which can remotely operate by using the application of a smartphone. It has been predicted that the minimization of the consumption of the freshwater in the targeted area of human farming will result in a significant increase in the economic and environmental benefits achieved from this area of farming.

It was assumed that, the proposed study mainly tends to be utilized to irrigate Alfalfa in Kuwait. It is worthy to mention that, the same irrigation system can be used for other planting projects. The decision was taken to consider data released officially by FAO to make the study more realized. It was assumed that, the Alfalfa consumed 1600 mm^3 of water until achieving total growth, which is the maximum value due to the high ambient temperature in Kuwait. The assumed data and specifications of the farm are presented in the Appendix D (Matlab code).

3.6. Multi Objective Approach

Generally, a set of technologies and ideas are suggested by an engineer in order to fit with such applications for the purpose of enhancing the environmental and economic benefits. It is required to compare these technologies and ideas with each other based on a set of requirements as well as specifications which have been stated by the clients. For successful implementation of an exact comparison between the suggested technologies and ideas, it is required to use a smart approach. Naturally, many advanced issues of engineering are multi-objective, that is because the fact that there is more than one goal of design that should be optimised. These objectives of the design may impose contradicting expectations on a system's technical and economic performance. It is required to formulate multiple objectives optimization problems in order to have the ability for trade-offs analysis among these conflicting design aims in addition to exploring feasible solutions for the design. It has been planned to use the multi-objective approach in order to compare the techniques and ideas that will be suggested for the purpose of minimising the consumption of freshwater during farming.

3.7. Assumptions

The technologies as well as suggestions that will be stated in the planned project will be considered mainly depending on the literature review presented in chapter two. A set of assumptions have been considered for the implementation of these project which are stated as follow;

I. A smart phone application should be used to regulate the flow control valve remotely.
II. Fresh water must be pumped into each of the four farming regions at the same time.
III. In 10 minutes, each farming area must be filled with fresh water.
IV. Each of the four agricultural regions has an identical 290 framing area that must be filled at the same time.
V. It's critical to keep the number of flow control valves in use to a minimum.
VI. To lower the overall cost of the proposed farming system, the chosen flow control valve should have a high degree of availability.

3.8. Results Analysis and Discussions

The results obtained from the simulation that is planned to be performed in the previous stage will be analysed and discussed in order to provide aid in presenting the obtained results via satisfying the main aim of this project. In this stage, there will be a detailed analysis and discussion for the purpose of forecasting the smart farming system's performance in addition to its economic feasibility which is possible to be estimated based on determining the system initial and running cost as well as the project payback period

3.9. Conclusion and Recommendations

This last phase mostly entails describing the concluding points in order for readers to comprehend the study's findings. It's also essential to reflect on showing the feasibility of the system of smart farming that was built in the suggested research. A set of suggestions was also selected to be offered for the decision making and for future scientific research, which is expected to aid in the understanding of the proposed study.

3.10. Commercial flow control valves

By surveying the market, different flow control valves were recommended to be compared with the proposed design. For example, the following flow control valve (40-01 & 640-01 Rate of Flow Control Valve) was advantaged by its precise operation and accurate control of the fluids flow through (cla-val, 2022).

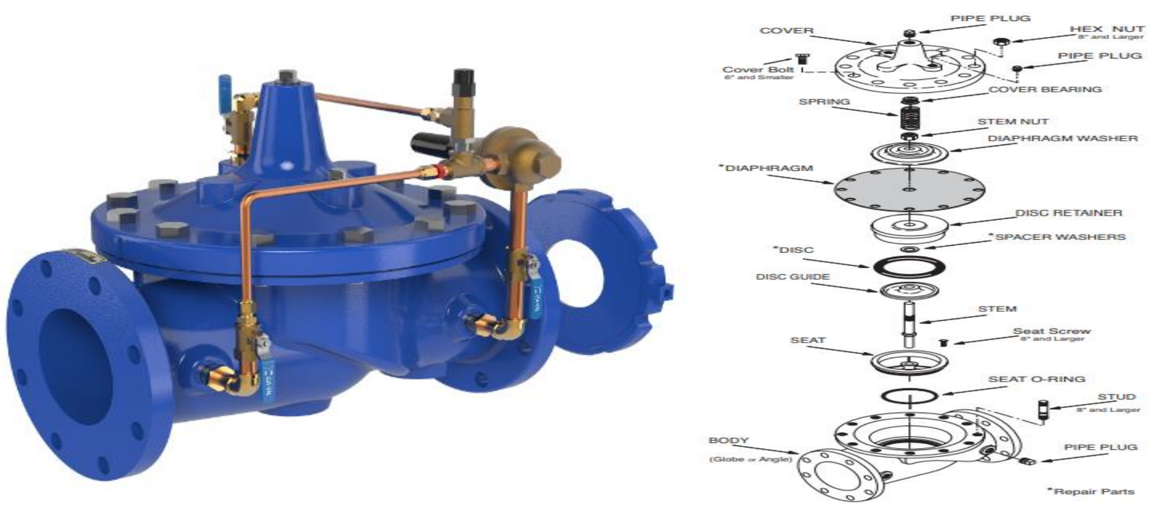

Figure 3-10. The first case study considered in the proposed research (cla-val, 2022).

The one way flow control valve shown in the figure below is characterized by its very low initial cost comparing with other types of control valve. In addition, it is characterized by its low material consumption that results in fewer emissions to be released during the manufacturing process (festo, 2021).

Figure 3-11. The second case study considered in the proposed research (festo, 2021).

Another flow control valve was considered in the proposed study which is advantaged by its higher reliability (tvnvalve, 2021).

Figure 3-12. The third case study considered in the proposed research (tvnvalve, 2021).

Chapter Four: Results analysis and discussions

4.1. Material comparison

For the three considered materials, it was estimated that, Polyester is estimated to allow achieving the highest mechanical performance as the yield strength for it is much higher than the ABS or PLA materials. Figure 4.2 compares among materials the three plastic materials considered in the material selection process in accordance with the yield strength (MPa) using CES.

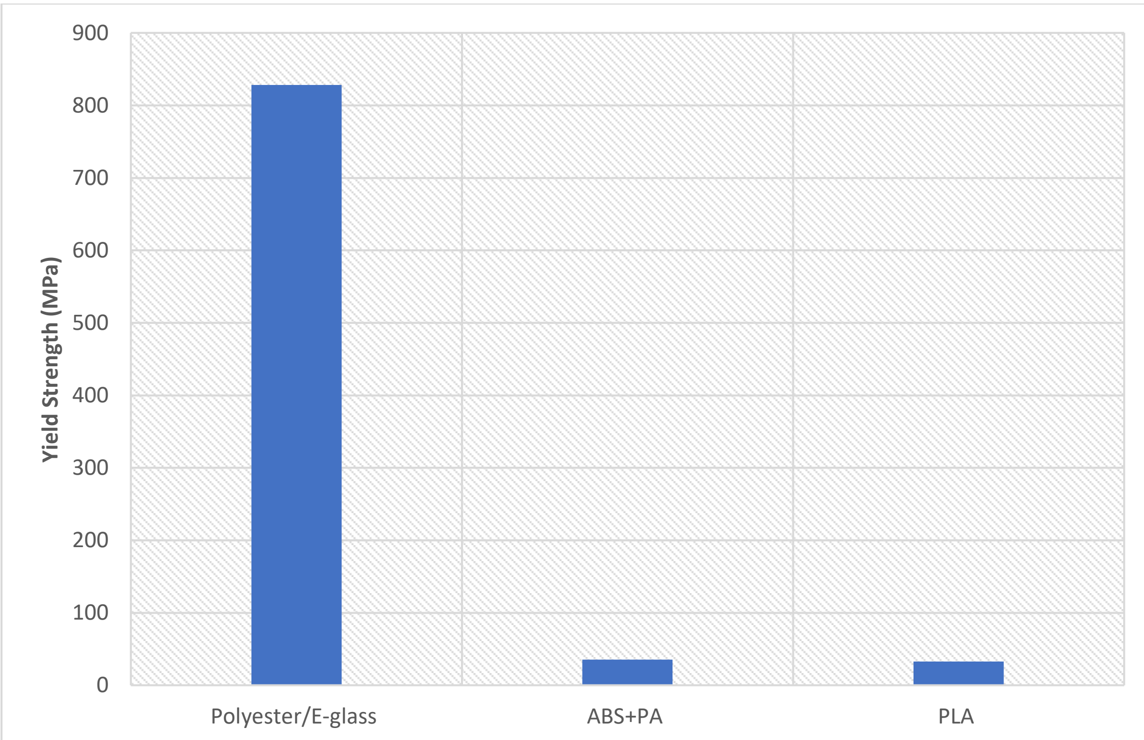

Figure 4-1. Comparison among the three plastic materials considered in the material selection process in accordance with the yield strength (MPa) using CES.

Polyester is estimated to allow achieving the highest fracture resistance as the fracture toughness for it is much higher than the ABS or PLA materials. Figure 4.3 compares among materials the three plastic materials considered in the material selection process in accordance with the Fracture toughness ($Pa.m^{0.5}$) using CES.

Also, Polyester is estimated to allow achieving the highest fatigue strength as it is much higher than the ABS or PLA materials. Figure 4.4 compares among materials the three plastic materials considered in the material selection process in accordance with the Fatigue strength (MPa) using CES.

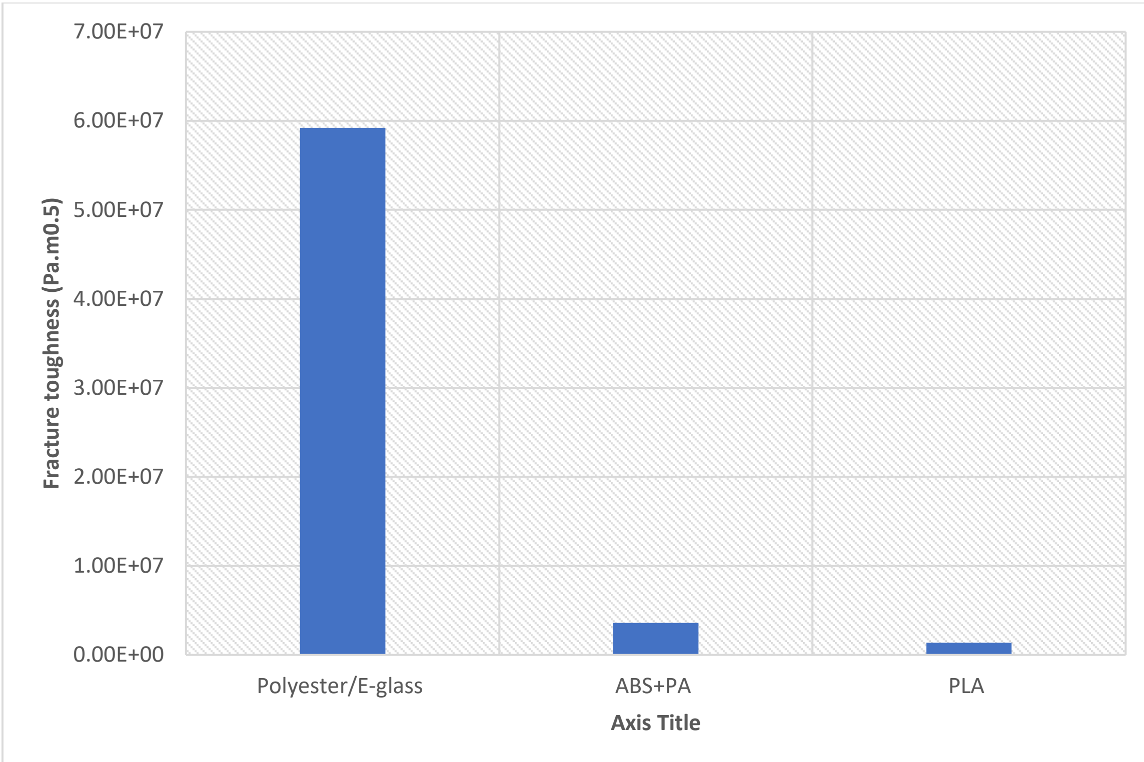

Figure 4-2. Comparison among the three plastic materials considered in the material selection process in accordance with the Fracture toughness (Pa.m0.5) using CES.

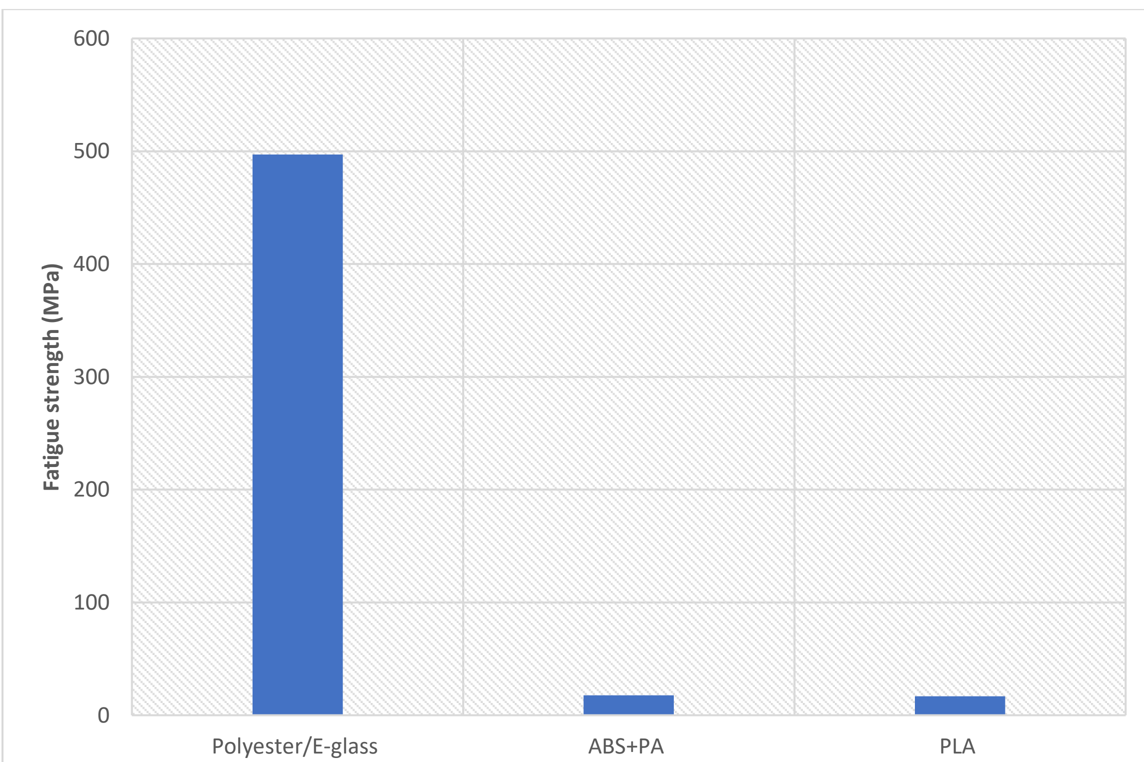

Figure 4-3. Comparison among the three plastic materials considered in the material selection process in accordance with the Fatigue strength (MPa) using CES.

On one hand, density of ABS was estimated to achieve the best performance (lowest weight) while its price is the highest that results in reducing the economic benefits. On the other hand, Polyester material had the lowest price with the relatively maximum density.

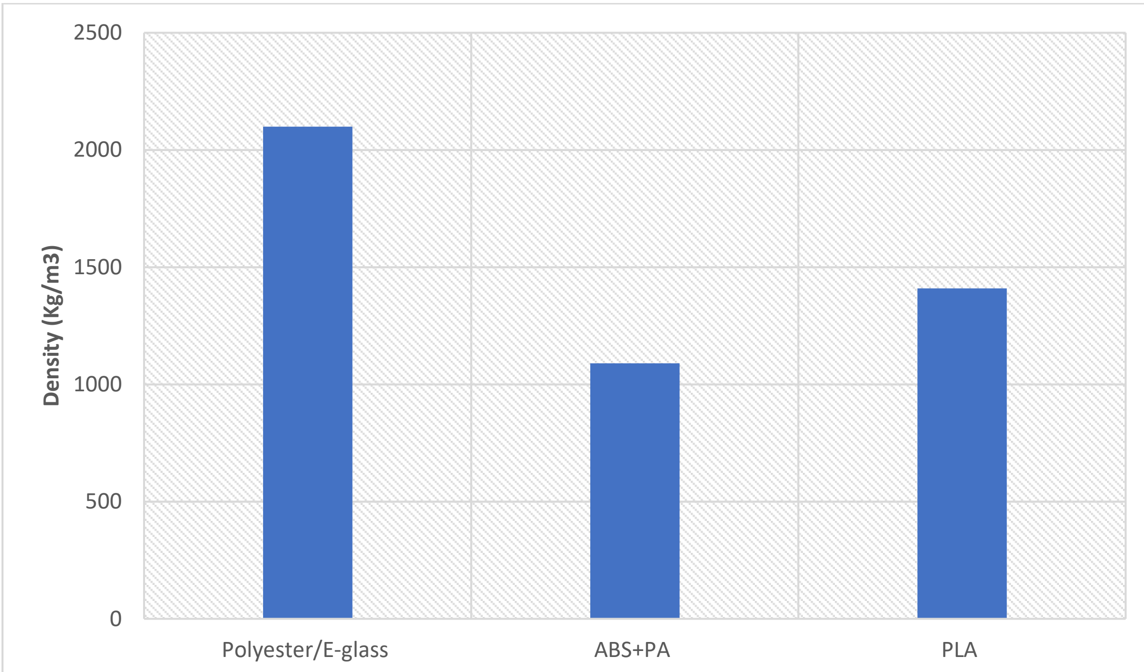

Figure 4-4. Comparison among the three plastic materials considered in the material selection process in accordance with the Density (Kg/m3) using CES.

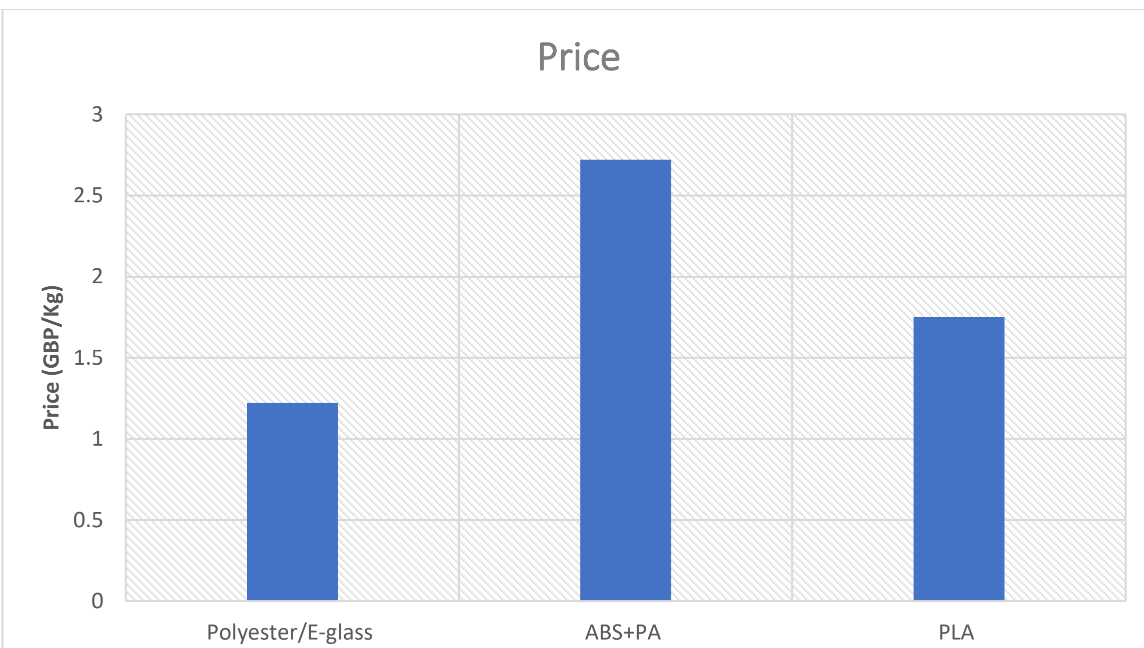

Figure 4-5. Comparison among the three plastic materials considered in the material selection process in accordance with the Price (GBP/Kg) using CES.

On one hand, CO_2 footprint of ABS was estimated to be high with energy consumption that is very high comparing with other materials. On the other hand, CO_2 footprint of PLA was estimated to be low with energy consumption that is the lowest comparing with other materials.

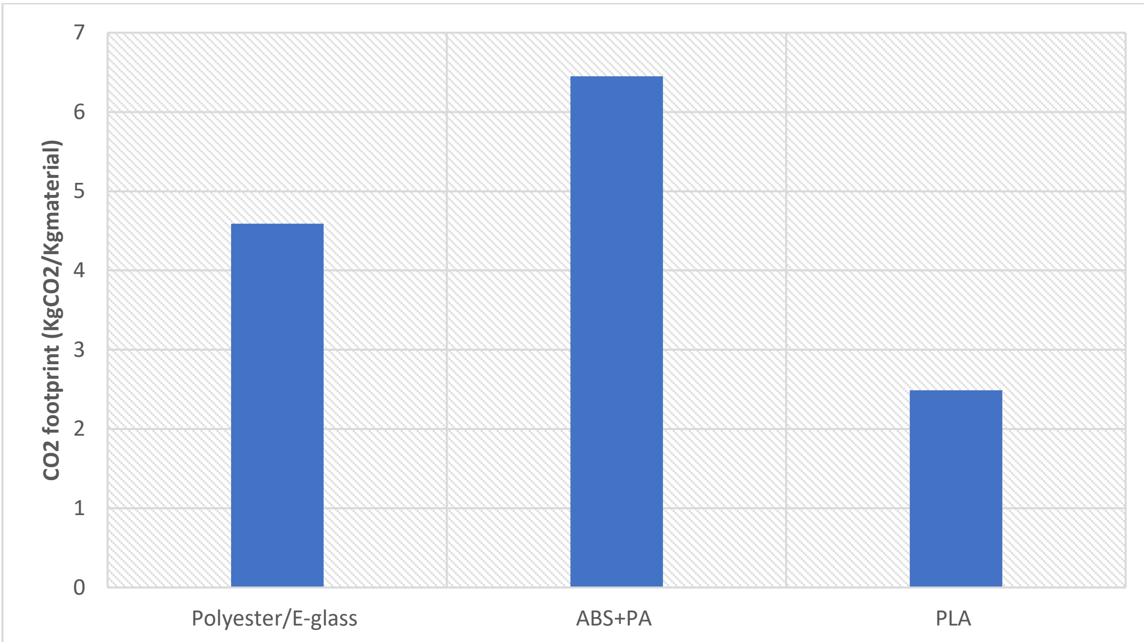

Figure 4-6. Comparison among the three plastic materials considered in the material selection process in accordance with the CO_2 footprint (KgCO2/Kgmaterial) using CES.

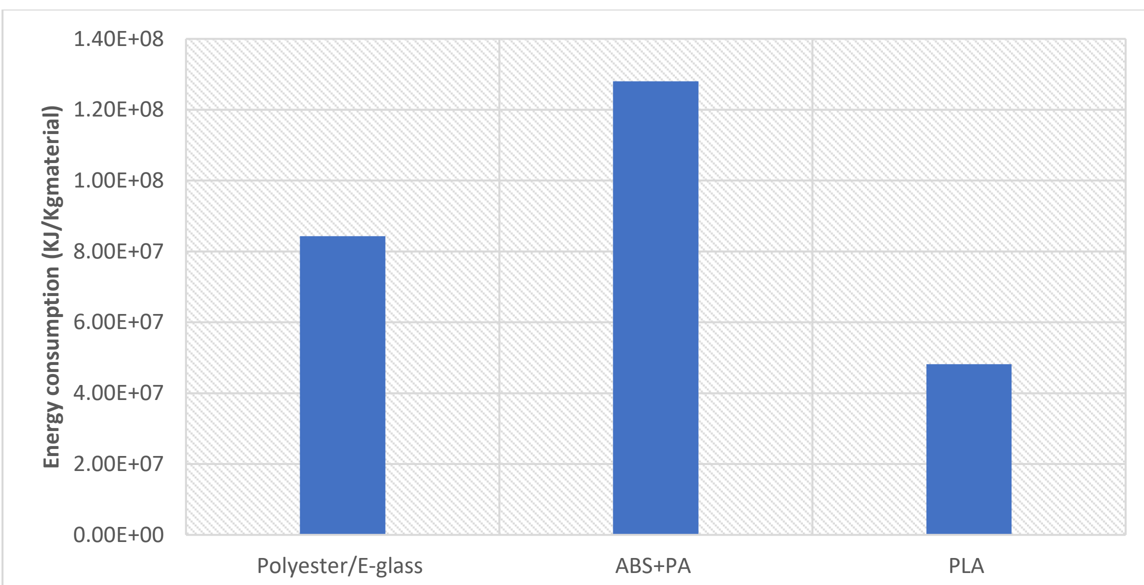

Figure 4-7. Comparison among the three plastic materials considered in the material selection process in accordance with the Energy consumption (KJ/Kgmaterial) using CES.

The decision was taken to consider Polyester material as being the most suitable one, which provides very high mechanical performance with moderate cost and environmental impact.

4.2. Eco Audit results

Obtained results from the eco audit study is estimated to help in predicting the environmental negative effect of the manufacturing process of the flow control valve.

4.2.1. Polyester material

In case of using polyester material in manufacturing the flow control valve, obtained results allowed predicting the following;

1. In accordance with the Carbon Footprint, it was estimated that, the material fabrication resulted in emitting 1.2 Kg of CO_2 gas while the manufacturing of the flow control valve using injection moulded technique emitted 0.662 Kg of CO_2 gas. Ending the life of the flow control valve was estimated to result in emitting 0.172 Kg of CO_2 gas and the transportation from Asia to Europe emits 0.033 Kg of CO_2. Figure 4.8 shows the predicted CO_2 footprint of the 3D modelled flow control valve.

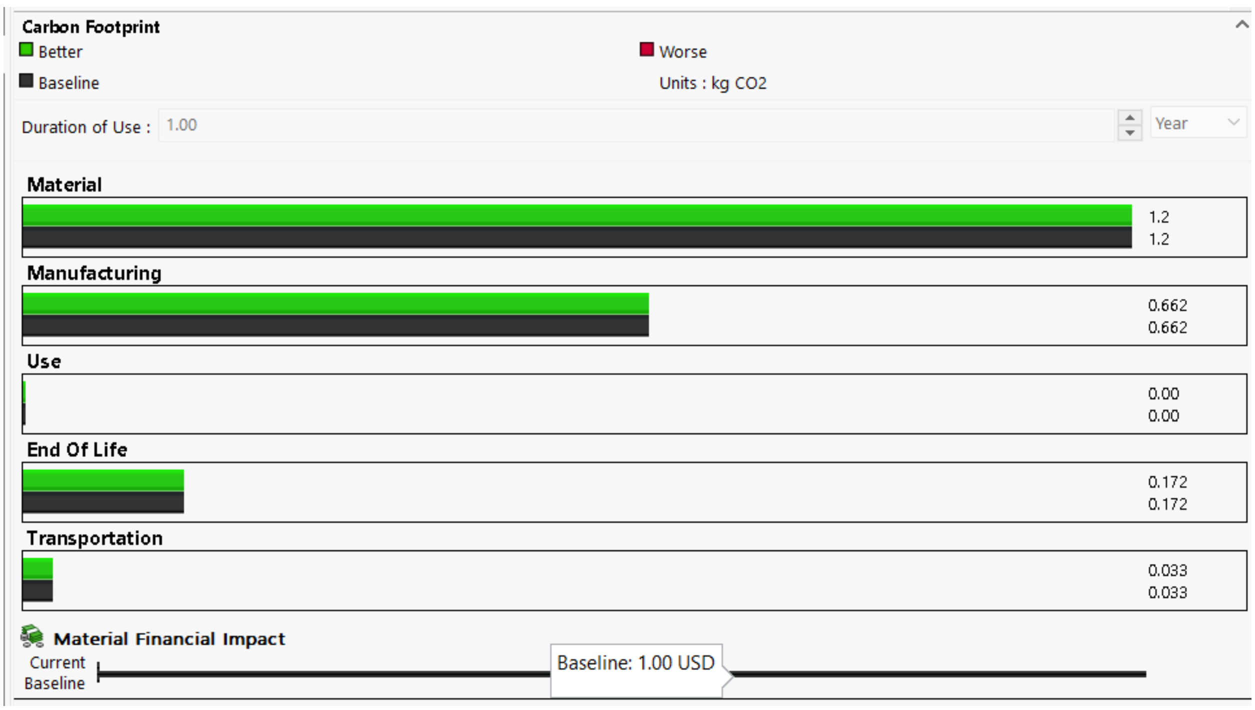

Figure 4-8. The predicted CO_2 footprint for each stage of the 3D modelled flow control valve made of Polyester material.

2. In accordance with the energy consumption, it was estimated that, the material fabrication resulted in consuming 24 MJ gas while the manufacturing of the flow control valve using injection moulded technique consumed 8.8 MJ. Ending the life of the flow control valve was estimated to result in consuming 0.128 MJ and the transportation from Asia to Europe

consumes 0.468 MJ. Figure 4.9 shows the predicted energy consumption of the 3D modelled flow control valve in case of the material used is polyester.

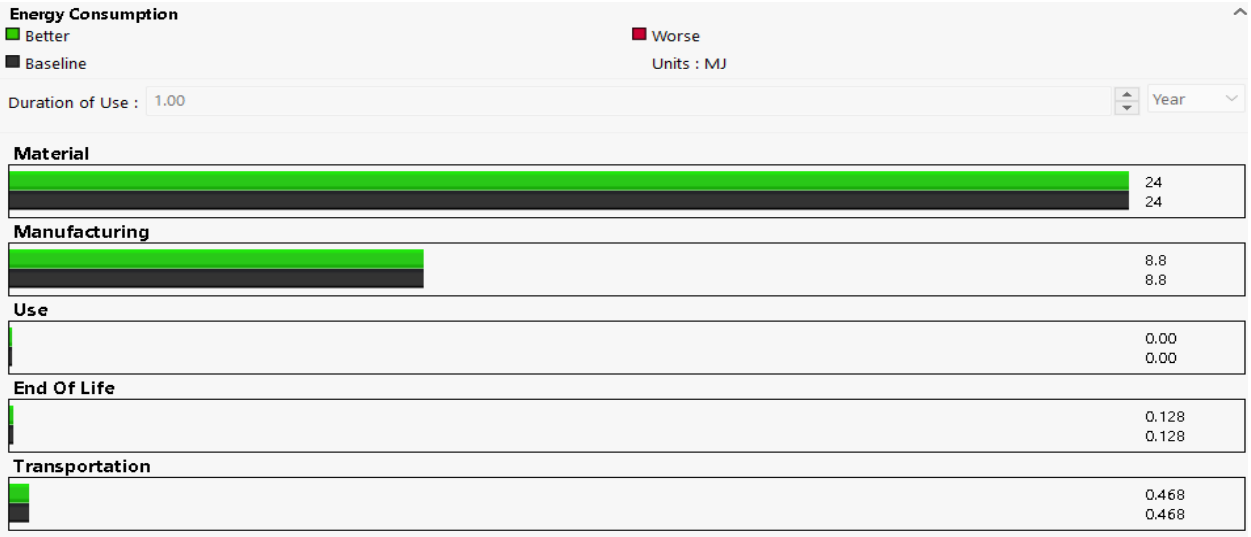

Figure 4-9. The predicted energy consumption for each stage of the 3D modelled flow control valve made of Polyester material.

3. In accordance with the air acidification, it was estimated that, the material fabrication resulted in emitting 2.1 x10^{-3} Kg of SO_2 gas while the manufacturing of the flow control valve using injection moulded technique emitted 8.7 x10^{-3} Kg of SO_2 gas. Ending the life of the flow control valve was estimated to result in emitting 9.9 x10^{-5} Kg of SO_2 gas and the transportation from Asia to Europe emits 4.3 x10^{-4} Kg of SO_2. Figure 4.10 shows the predicted SO_2 emissions for each stage for the 3D modelled flow control valve.

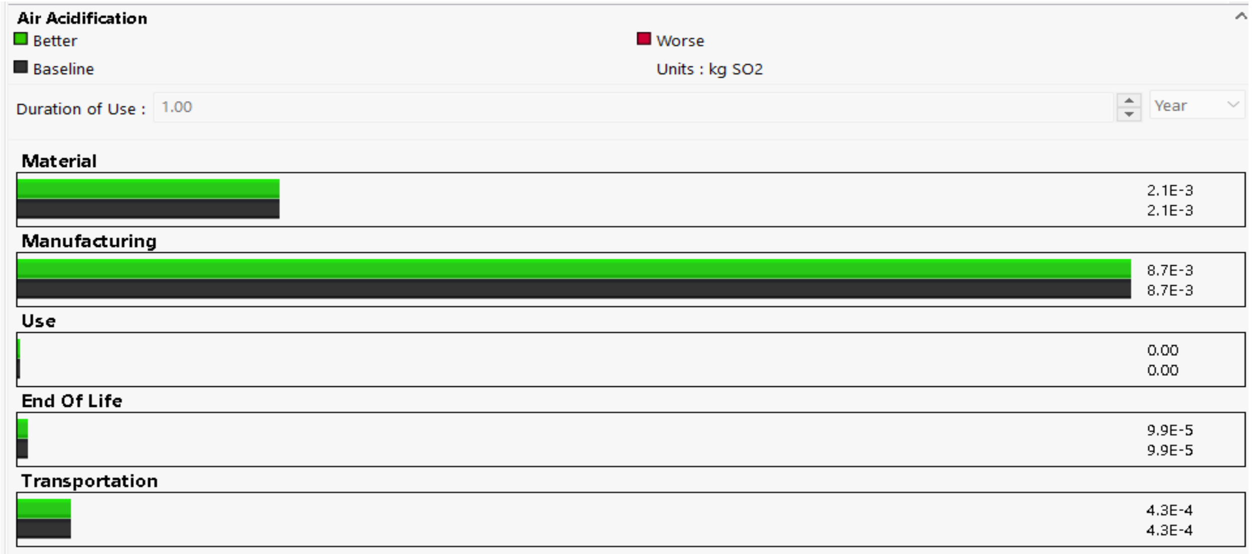

Figure 4-10. The predicted air acidification for each stage of the 3D modelled flow control valve made of Polyester material.

4. In accordance with the water eutrophication, it was estimated that, the material fabrication resulted in emitting 3.4 x10^{-4} Kg of PO_4 while the manufacturing of the flow control valve using injection moulded technique emitted 3.2 x10^{-4} Kg of PO_4 gas. Ending the life of the flow control valve was estimated to result in emitting 1.7 x10^{-4} Kg of PO_4 gas and the transportation from Asia to Europe emits 5.5 x10^{-5} Kg of PO_4. Figure 4.11 shows the predicted PO_4 emissions for each stage for the 3D modelled flow control valve.

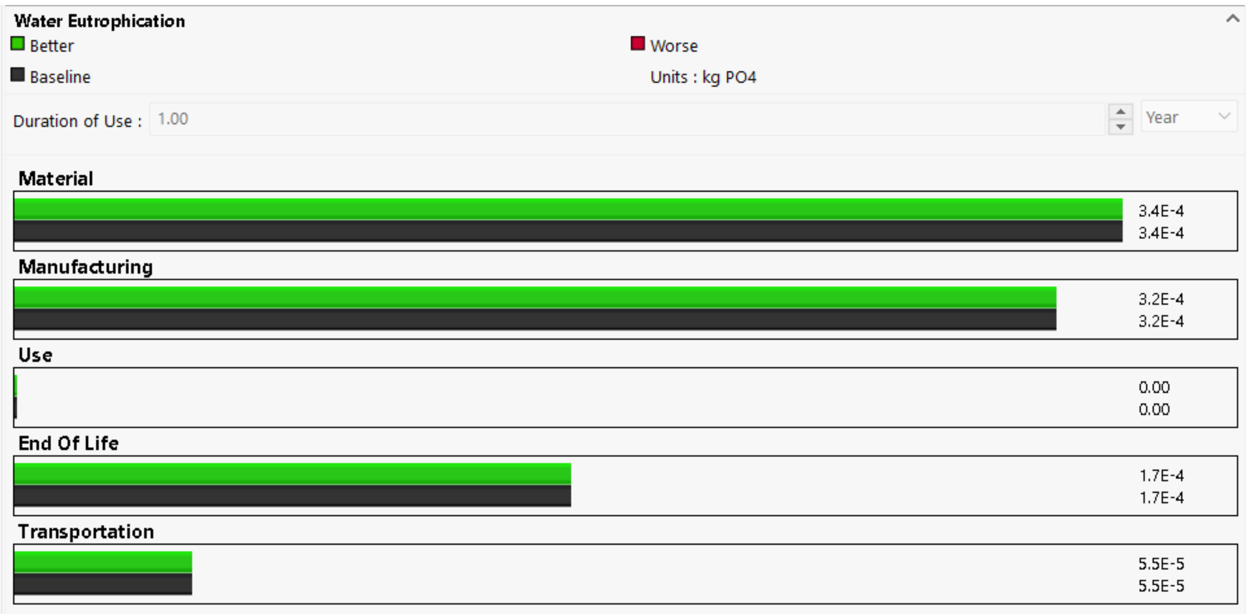

Figure 4-11. The predicted water eutrophication for each stage of the 3D modelled flow control valve made of Polyester material.

4.2.2. ABS material

In case of using ABS material in manufacturing the flow control valve, obtained results allowed predicting the following;

1. In accordance with the Carbon Footprint, it was estimated that, the material fabrication resulted in emitting 0.815 Kg of CO2 gas while the manufacturing of the flow control valve using injection moulded technique emitted 0.6 Kg of CO2 gas. Ending the life of the flow control valve was estimated to result in emitting 0.151 Kg of CO2 gas and the transportation from Asia to Europe emits 0.029 Kg of CO2. Figure 4.12 shows the predicted CO2 footprint of the 3D modelled flow control valve.

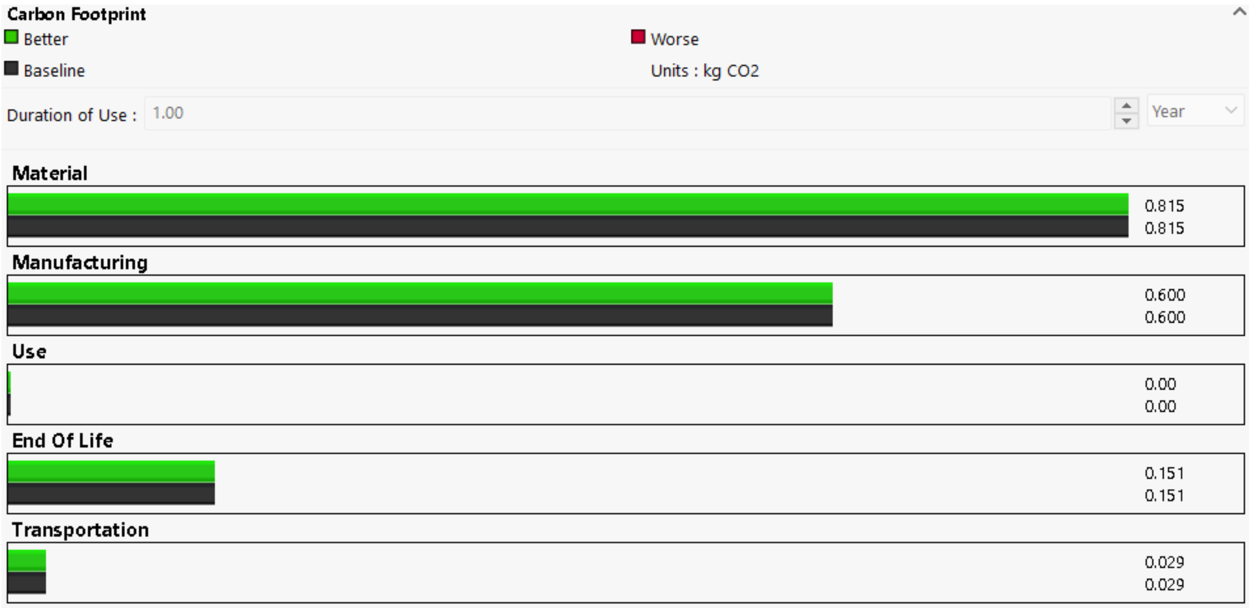

Figure 4-12. The predicted CO2 footprint for each stage of the 3D modelled flow control valve made of ABS material.

2. In accordance with the energy consumption, it was estimated that, the material fabrication resulted in consuming 20 MJ gas while the manufacturing of the flow control valve using injection moulded technique consumed 8.2 MJ. Ending the life of the flow control valve was estimated to result in consuming 0.113 MJ and the transportation from Asia to Europe consumes 0.411 MJ. Figure 4.13 shows the predicted energy consumption of the 3D modelled flow control valve in case of the material used is ABS.

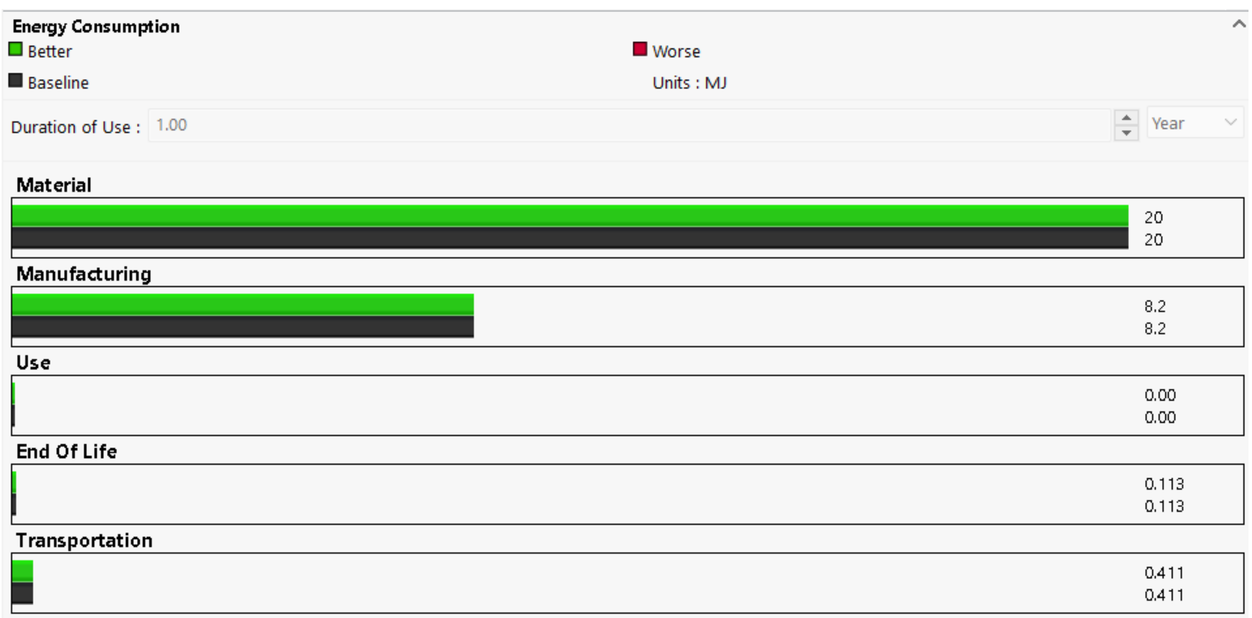

Figure 4-13. The predicted energy consumption for each stage of the 3D modelled flow control valve made of ABS material.

3. In accordance with the air acidification, it was estimated that, the material fabrication resulted in emitting 1.8 x10^{-3} Kg of SO_2 gas while the manufacturing of the flow control valve using injection moulded technique emitted 7.9 x10^{-3} Kg of SO_2 gas. Ending the life of the flow control valve was estimated to result in emitting 8.7 x10^{-5} Kg of SO_2 gas and the transportation from Asia to Europe emits 3.8 x10^{-4} Kg of SO_2. Figure 4.14 shows the predicted SO_2 emissions for each stage for the 3D modelled flow control valve.

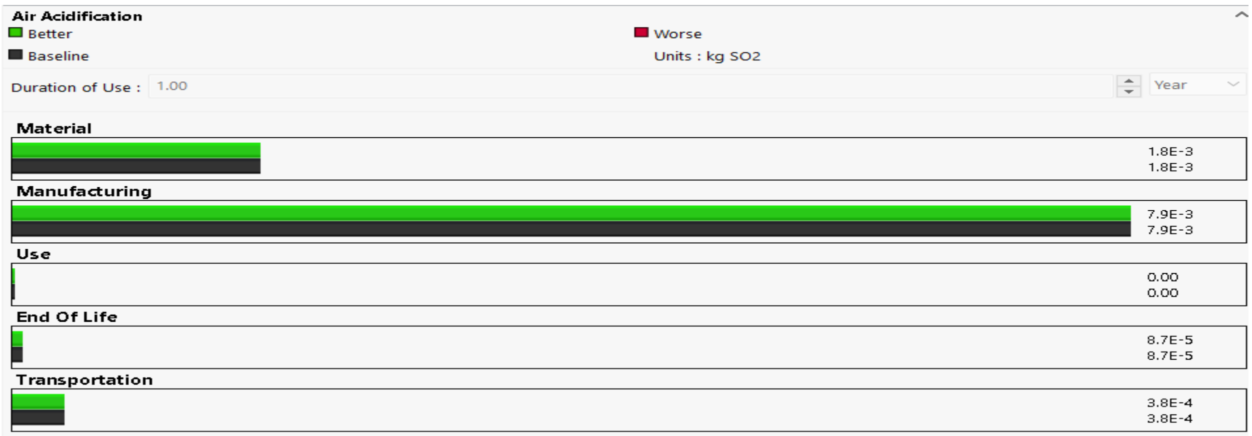

Figure 4-14. The predicted air acidification for each stage of the 3D modelled flow control valve made of ABS material.

4. In accordance with the water eutrophication, it was estimated that, the material fabrication resulted in emitting 3.1 x10^{-4} Kg of PO_4 while the manufacturing of the flow control valve using injection moulded technique emitted 2.9 x10^{-4} Kg of PO_4 gas. Ending the life of the flow control valve was estimated to result in emitting 1.5 x10^{-4} Kg of PO_4 gas and the transportation from Asia to Europe emits 4.9 x10^{-5} Kg of PO_4. Figure 4.15 shows the predicted PO_4 emissions for each stage for the 3D modelled flow control valve.

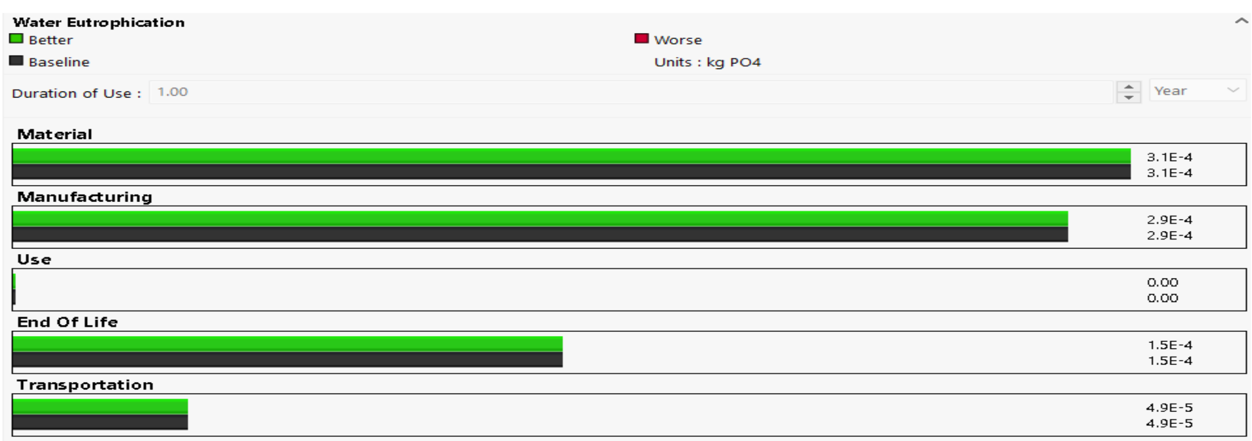

Figure 4-15. The predicted water eutrophication for each stage of the 3D modelled flow control valve made of ABS material.

4.2.3. PLA material

In case of using PLA material in manufacturing the flow control valve, obtained results allowed predicting the following;

1. In accordance with the Carbon Footprint, it was estimated that, the material fabrication resulted in emitting 2.5 Kg of CO2 gas while the manufacturing of the flow control valve using injection moulded technique emitted 0.647 Kg of CO2 gas. Ending the life of the flow control valve was estimated to result in emitting 0.166 Kg of CO2 gas and the transportation from Asia to Europe emits 0.032 Kg of CO2. Figure 4.16 shows the predicted CO2 footprint of the 3D modelled flow control valve.

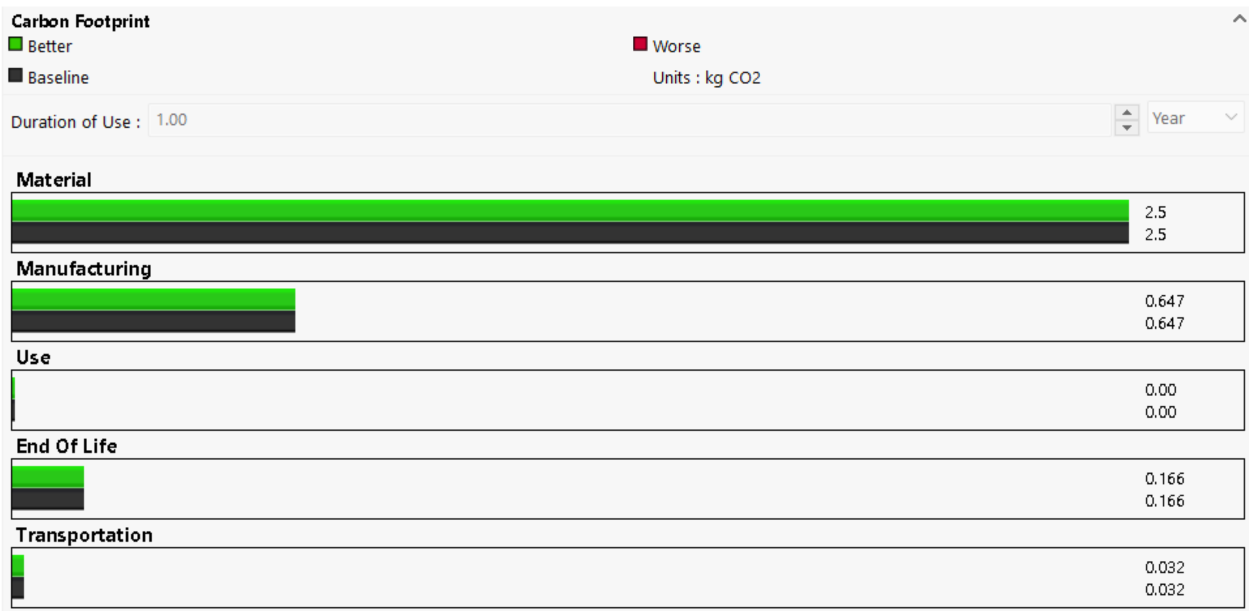

Figure 4-16. The predicted CO2 footprint for each stage of the 3D modelled flow control valve made of PLA material.

2. In accordance with the energy consumption, it was estimated that, the material fabrication resulted in consuming 46 MJ gas while the manufacturing of the flow control valve using injection moulded technique consumed 8.6 MJ. Ending the life of the flow control valve was estimated to result in consuming 0.124 MJ and the transportation from Asia to Europe consumes 0.452 MJ. Figure 4.17 shows the predicted energy consumption of the 3D modelled flow control valve in case of the material used is PLA.

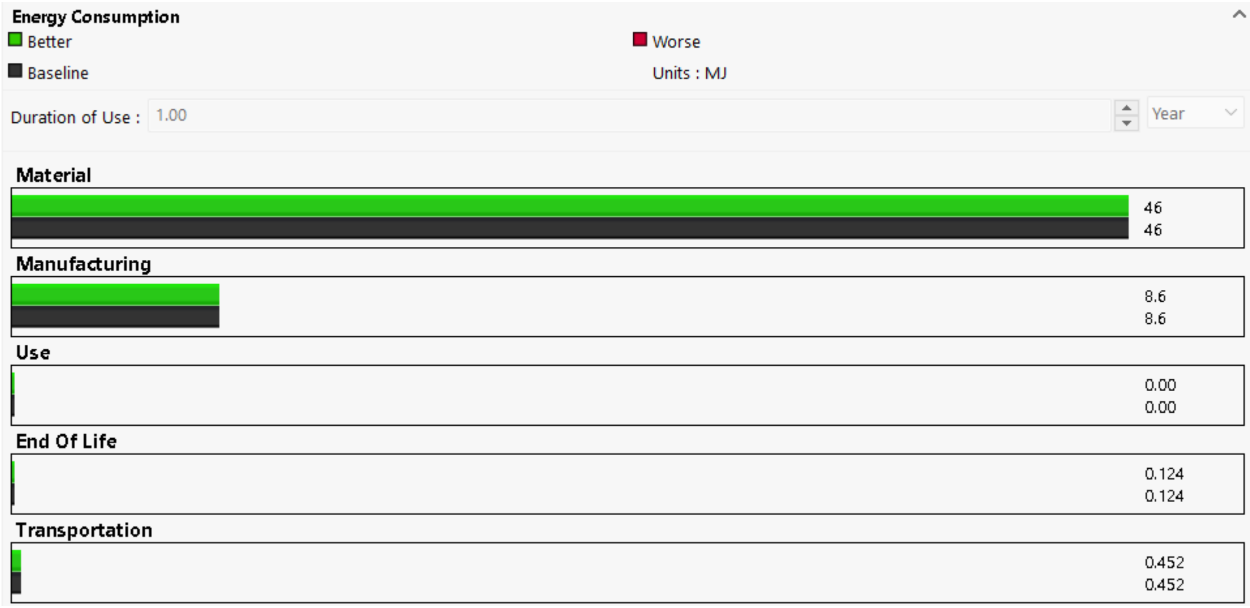

Figure 4-17. The predicted energy consumption for each stage of the 3D modelled flow control valve made of PLA material.

3. In accordance with the air acidification, it was estimated that, the material fabrication resulted in emitting 3.8 x10^{-3} Kg of SO_2 gas while the manufacturing of the flow control valve using injection moulded technique emitted 8.6 x10^{-3} Kg of SO_2 gas. Ending the life of the flow control valve was estimated to result in emitting 9.6 x10^{-5} Kg of SO_2 gas and the transportation from Asia to Europe emits 4.2 x10^{-4} Kg of SO_2. Figure 4.18 shows the predicted SO_2 emissions for each stage for the 3D modelled flow control valve.

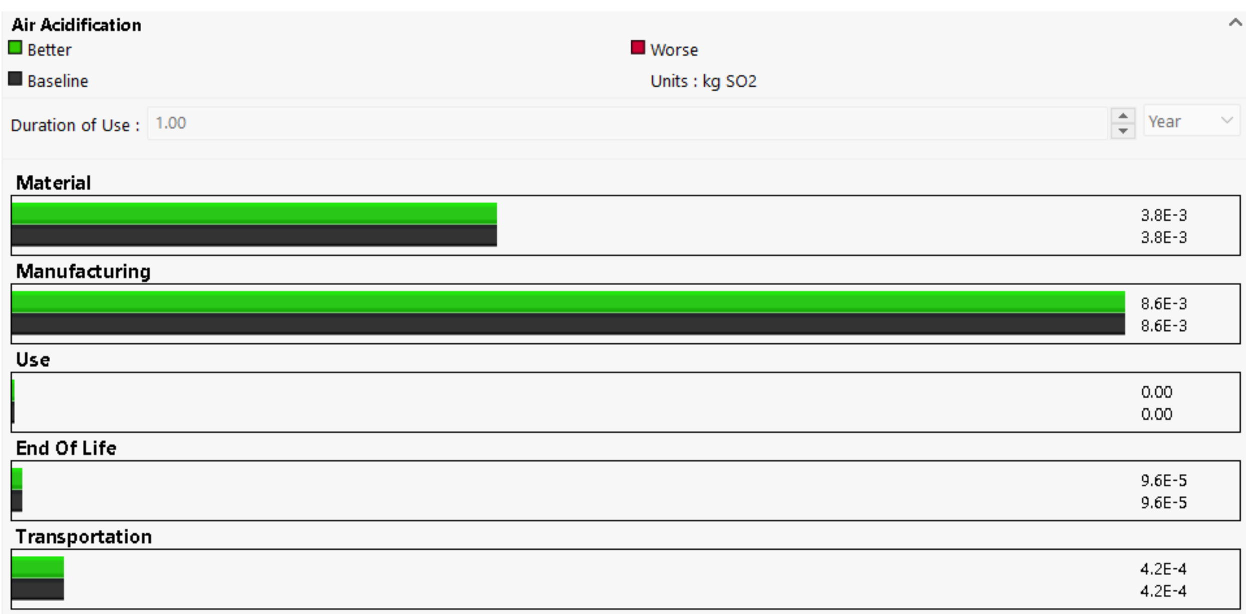

Figure 4-18. The predicted air acidification for each stage of the 3D modelled flow control valve made of PLA material.

4. In accordance with the water eutrophication, it was estimated that, the material fabrication resulted in emitting 4.4 $x10^{-4}$ Kg of PO_4 while the manufacturing of the flow control valve using injection moulded technique emitted 3.2 $x10^{-4}$ Kg of PO_4 gas. Ending the life of the flow control valve was estimated to result in emitting 1.7 $x10^{-4}$ Kg of PO_4 gas and the transportation from Asia to Europe emits 5.4 $x10^{-5}$ Kg of PO_4. Figure 4.19 shows the predicted PO_4 emissions for each stage for the 3D modelled flow control valve.

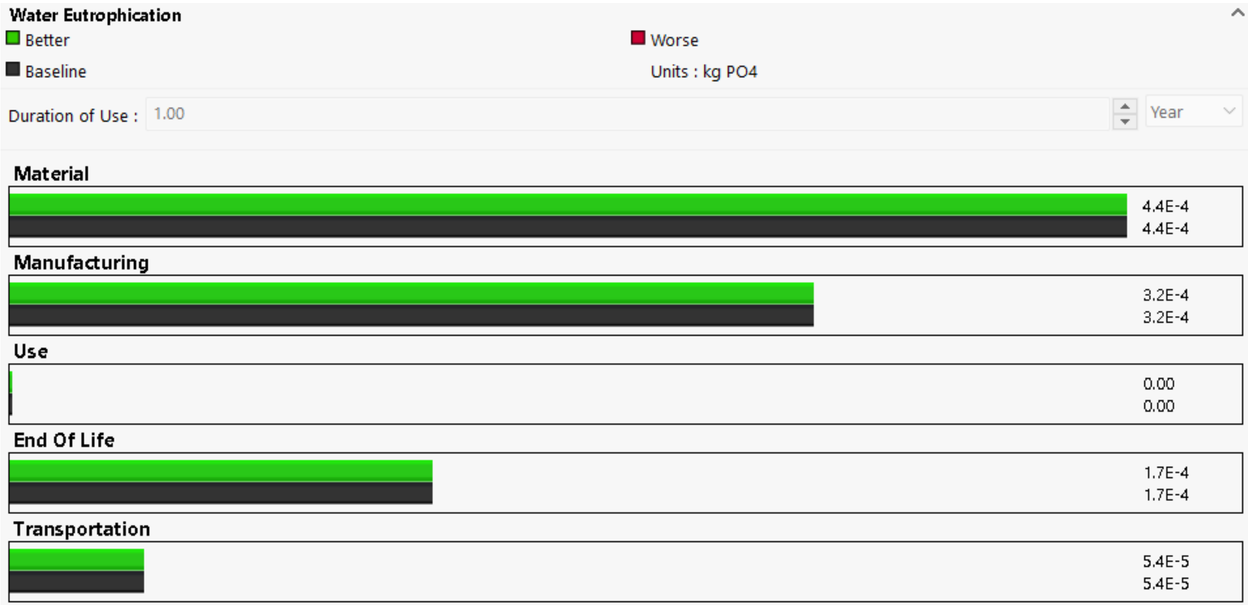

Figure 4-19. The predicted water eutrophication for each stage of the 3D modelled flow control valve made of PLA material.

4.3. Matlab results

The Matlab code mainly constructed so as to be able of predicting such parameters that vary respect to a group of characteristics that are presented as follows;

1. In accordance with the number of fields, it was predicted that, increasing number of fields is estimated to help in reducing the number of valves required for the irrigation process. Figure 4.20 shows the predicted effect of the number of fields on the required number of valves in case of farming Alfalfa in Kuwait. As it was predicted that, irrigating 68 farms require 37 flow control valves while irrigating 207 farms requires only 13 flow control valves.

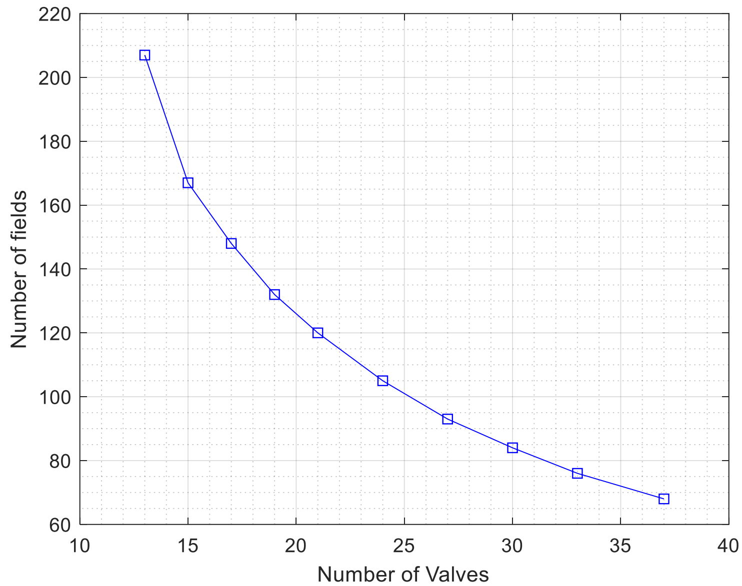

Figure 4-20. The predicted effect of the number of fields on the required number of valves in case of farming Alfalfa in Kuwait.

2. In accordance with the operation time, it was predicted that, increasing operation hours is estimated to help in reducing the number of valves required for the irrigation process. Unfortunately, increasing number of operating hours is estimated to result in consuming higher electrical power as well as applying more maintenance. Figure 4.20 shows the predicted effect of the number of operating hours over the day on the required number of valves in case of farming Alfalfa in Kuwait. As it was predicted that, irrigating a farm for 3.29 hour require 37 flow control valves while irrigating a farm for 10 operating hours requires only 13 flow control valves.

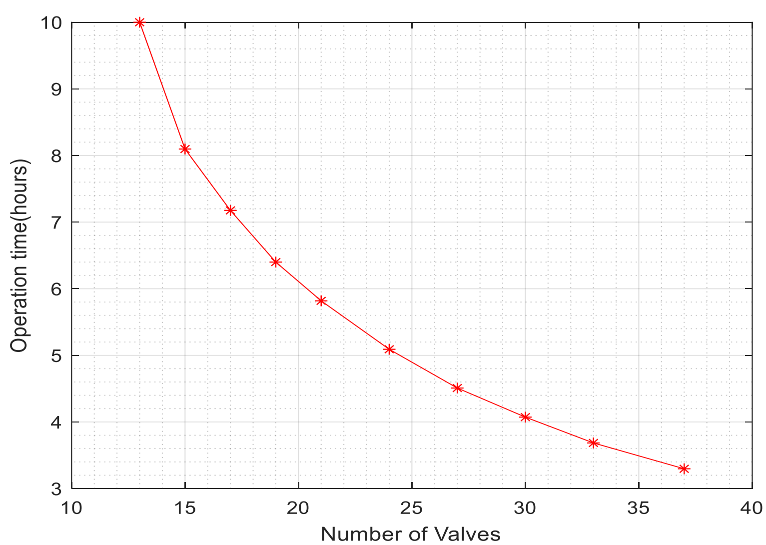

Figure 4-21. The predicted effect of the number of operating hours over the day on the required number of valves in case of farming Alfalfa in Kuwait.

3. In accordance with the water required up to end growing, it was predicted that, increasing water required up to end growing is estimated to help in reducing the growing period. The rate of reduction was predicted to be linear as it is shown in figure 4.21, which shows the predicted effect of the water required up to end growing on the period of growing in case of farming Alfalfa in Kuwait.

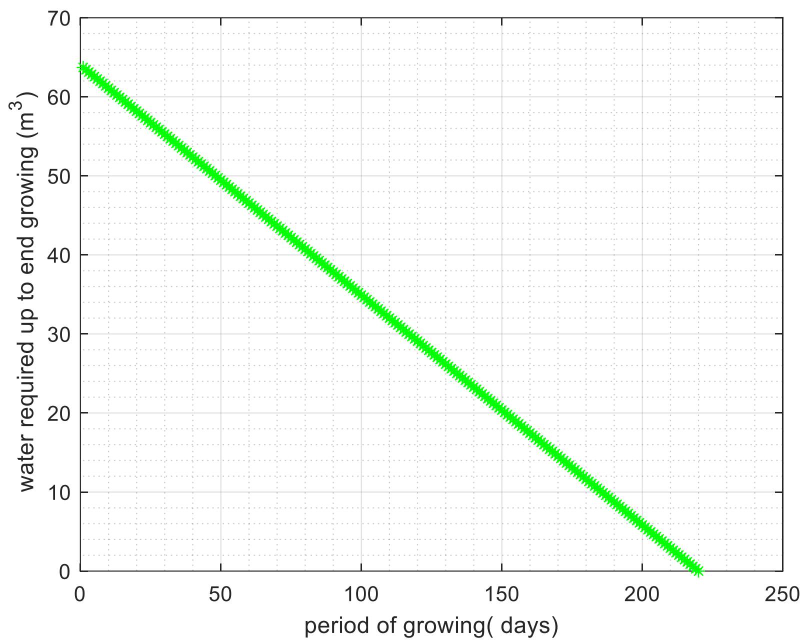

Figure 4-22. The predicted effect of the water required up to end growing on the period of growing in case of farming Alfalfa in Kuwait.

4. In accordance with the accumulated water consumption, it was predicted that, increasing accumulated water consumption is estimated to help in increasing the growing period. The rate of increase was predicted to be linear as it is shown in figure 4.23, which shows the predicted effect of the accumulated water consumption on the period of growing in case of farming Alfalfa in Kuwait.

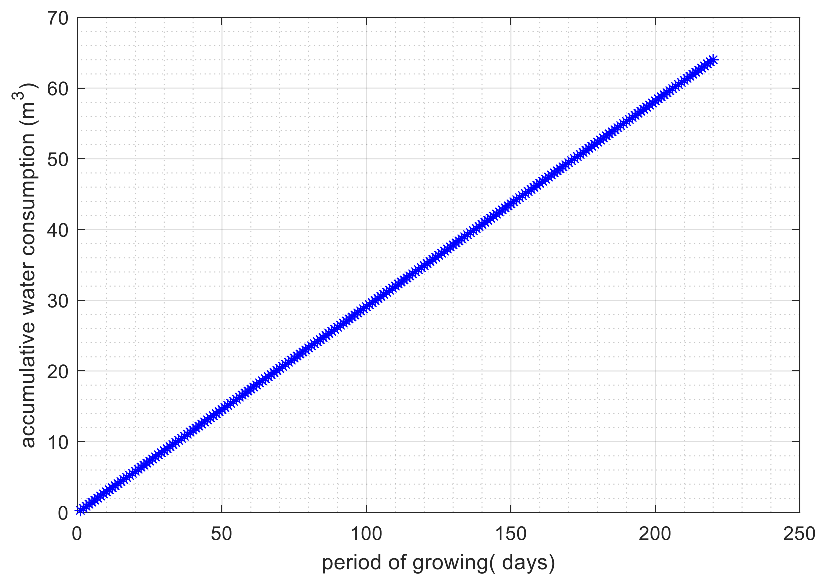

Figure 4-23. The predicted effect of the accumulated water consumption on the period of growing in case of farming Alfalfa in Kuwait.

5. In accordance with the number of fields can be irrigated using one valve daily, it was predicted that, increasing number of fields can be irrigated using one valve daily is estimated to help in increasing the flowrate of water. The rate of increase was predicted to be linear as it is shown in figure 4.24.

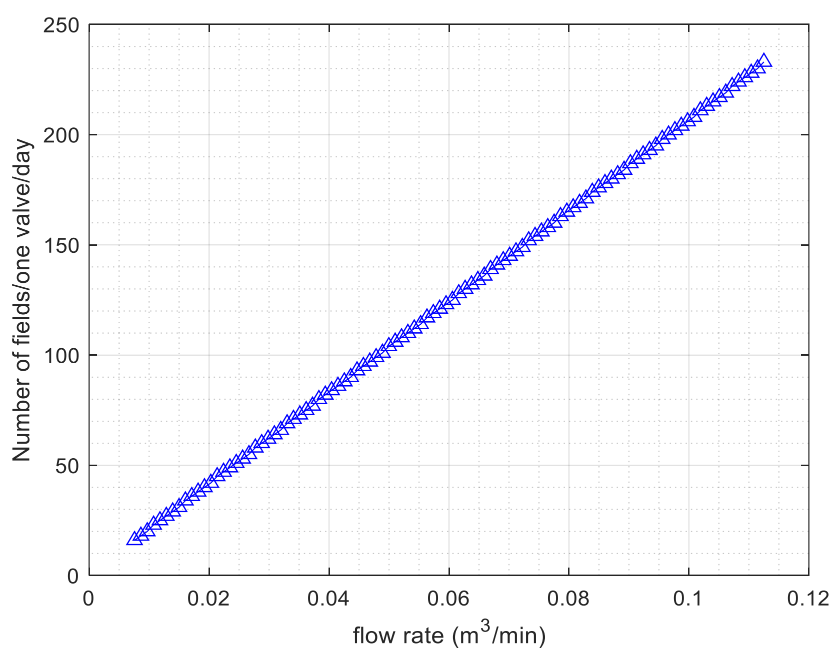

Figure 4-24. The predicted effect of the number of fields can be irrigated using one valve daily in case of farming Alfalfa in Kuwait.

6. In accordance with the flowrate of water, it was predicted that, increasing number of valves significantly effect on the flowrate of water. Figure 4.25 shows the predicted effect of the flowrate of water on the required number of valves in case of farming Alfalfa in Kuwait.

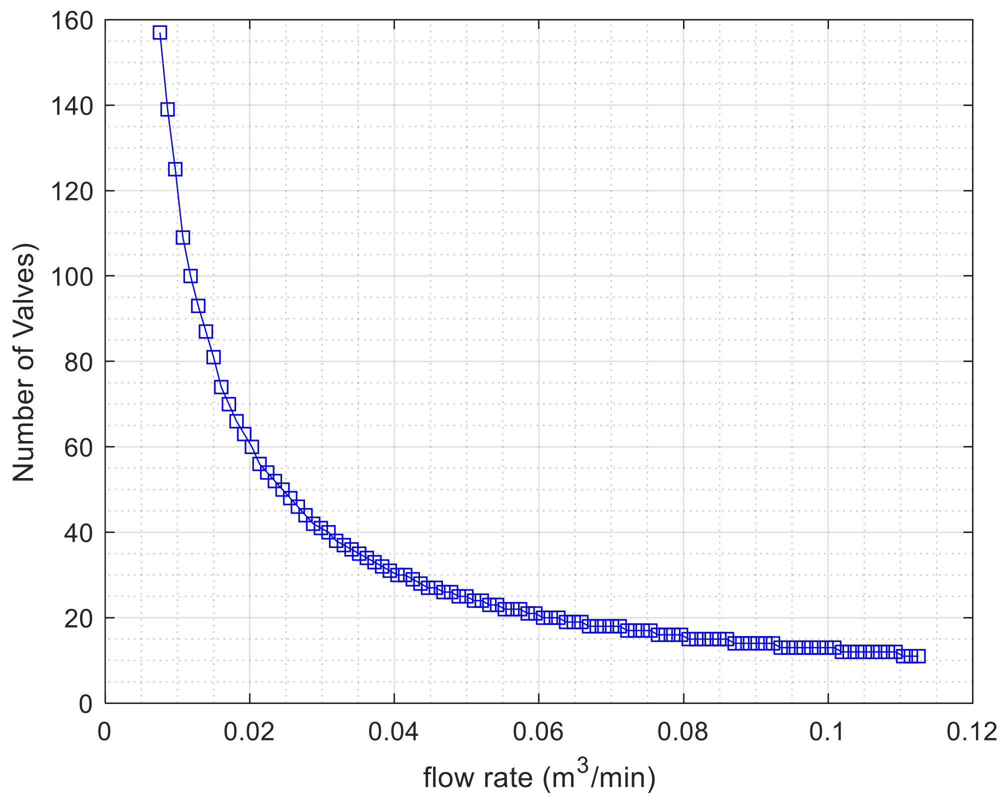

Figure 4-25. The predicted effect of the flowrate of water on the required number of valves in case of farming Alfalfa in Kuwait.

4.6. Discussions

The increased demand for water, combined with resource constraints caused by population growth and industrial development, results in a water crisis in several countries. In order to address this issue, consumption and demand management issues must be addressed in water distribution systems. One possible solution that has been proposed is the use of specific types of valves to reduce water consumption.

It is possible to regulate the flow in the valve by varying the resistance as the valve is stroked. This means that whenever the cross-sectional area changes. When the fluid from the pipeline moves into the smaller diameter of the valve orifice, the velocity increases to allow the mass to flow through the valve. The required energy to increase fluid flow velocity comes at the expense of pressure; the lowest pressure point is at the highest pressure point, which is the point where the valve has the smallest cross-section area. This is known as the "vena contracta." To demonstrate the low behaviour of the valve, a simplified orifice of the valve with a pipeline is used.

The material selection process had been applied allowed investigating a group of materials (thermoplastics) to be considered in the fabrication process of the flow control valve. The decision was taken to consider Polyester material as being the most suitable one, which provides very high mechanical performance with moderate cost and environmental impact.

Regarding the proposed system, it can be controlled the using Arduino system that can be simulated using Tinker CAD software. The utilized software is estimated to help in controlling the operation of the irrigation system remotely. The control system was designed to be as simple as it could be, which helps in reducing the initial cost of the system. A simple Arduino board was connected to a LCD monitor as it is shown in the following figure;

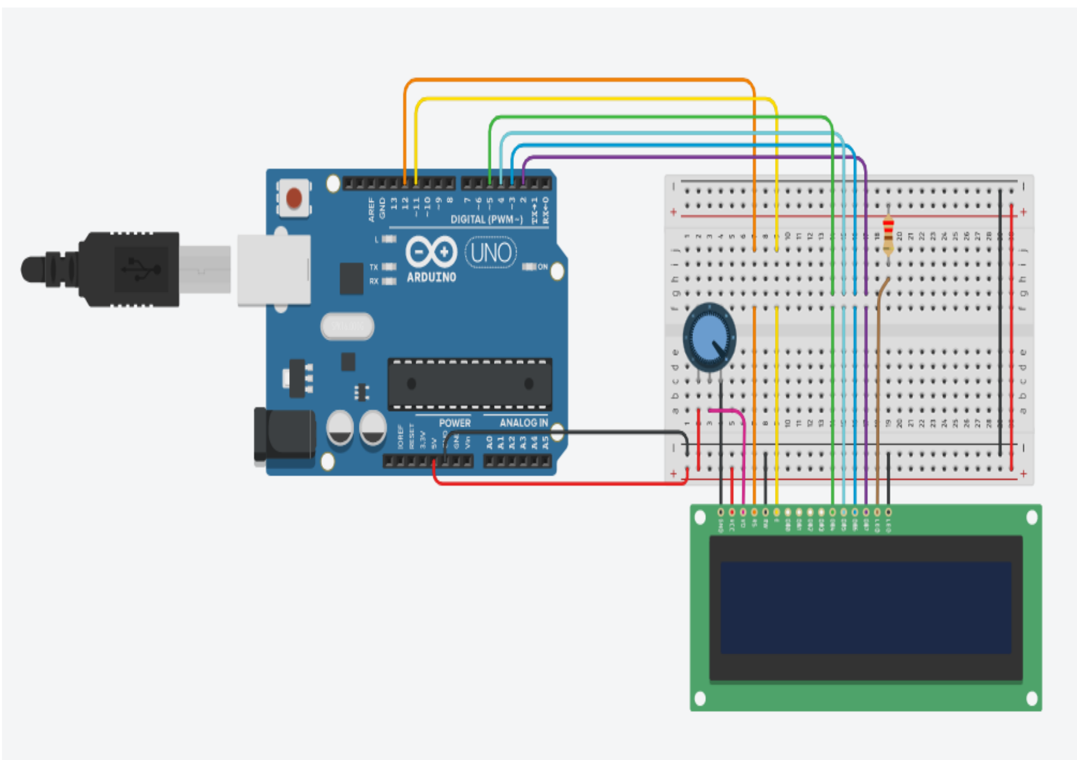

Figure 4-26. Connecting the monitoring LCD to the Arduino board.

The control system mainly planned to be operated based on the moisture of ambient air, which pushed towards installing a moisture sensor that is shown in the following figure.

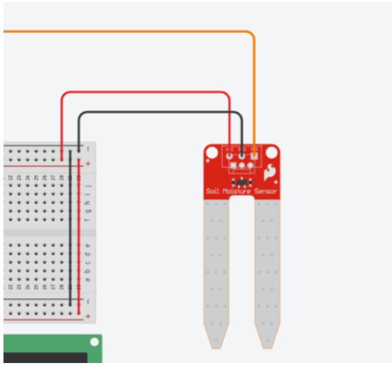

Figure 4-27. Installing a moisture sensor to the control system.

It is worthy to mention that, the proposed irrigation system requires installing a pump, which is evaluated in the control system as being a DC motor. Figure 4.28 shows the control circuit for the irrigation system using Tinker CAD. The power supply was used to control the supplied voltage to be 5 V.

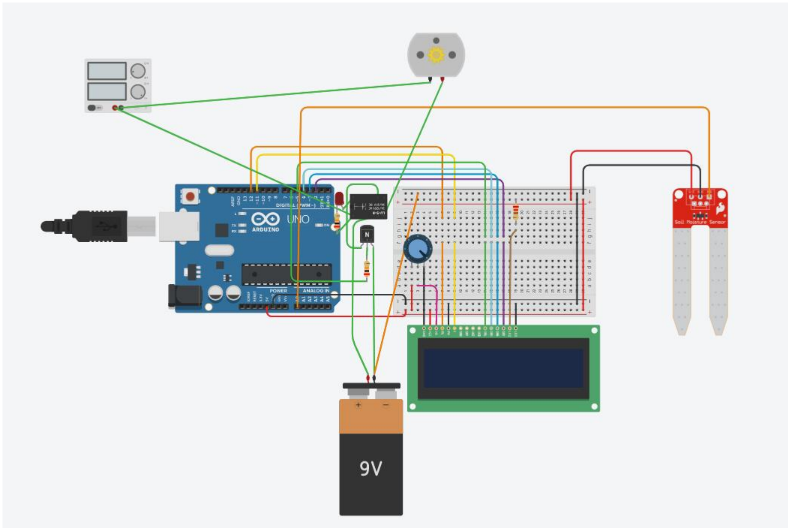

Figure 4-28. The control circuit for the irrigation system using Tinker CAD.

There are two main operating scenarios are expected to be considered in this system, which mainly subjected to the moisture percentage in the soil. These scenarios are presented as follows;

1. Scenario 1: in case of the soil moisture less than 40%, the circuit is connected to operate the pumps (DC motors) so as to able of irrigating the Alfalfa in the farm. Figure 4.29 shows the control circuit in case of the moisture is less than 40%.

2. Scenario 2: in case of the soil moisture higher than 40%, the circuit is disconnected to operate the pumps (DC motors) leading to reduce the water consumption. Figure 4.30 shows the control circuit in case of the moisture is higher than 40%.

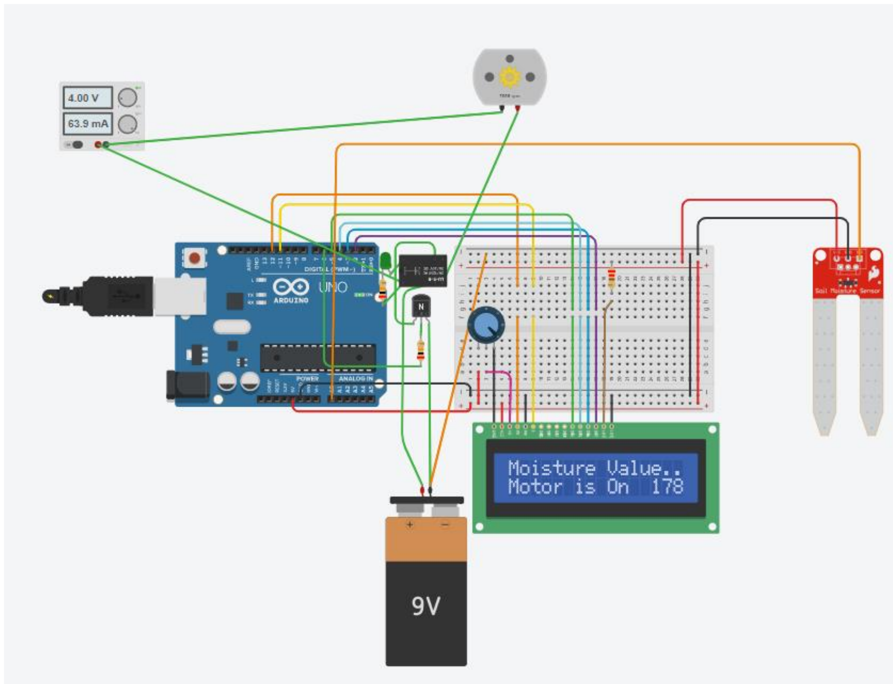

Figure 4-29. The control circuit in case of the moisture is less than 40 %.

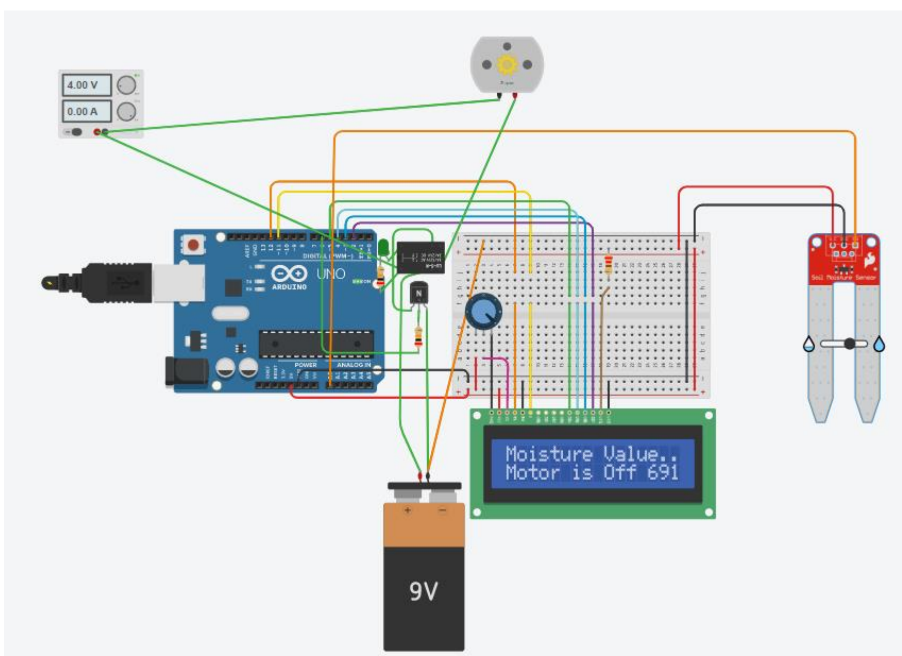

Figure 4-30. The control circuit in case of the moisture is higher than 40 %.

Chapter Five: Conclusion and recommendations

5.1. Conclusions

Water scarcity occurs in several countries as a result of increased demand for water combined with resource constraints caused by population growth and industrial development. To address this issue, water distribution systems must address consumption and demand management issues. The use of specific types of valves to reduce water consumption has been proposed as one possible solution.

The flow in the valve can be controlled by varying the resistance as the valve is stroked. That is, whenever the cross-sectional area changes. The velocity increases as the fluid from the pipeline moves into the smaller diameter of the valve orifice, allowing the mass to flow through the valve. The energy required to increase fluid flow velocity comes at the expense of pressure; the lowest pressure point is at the highest pressure point, which is the point with the smallest cross-section area of the valve. This is referred to as the "vena contracta." A simplified orifice of the valve with a pipeline is used to demonstrate the valve's low behaviour.

Polyester is estimated to have the highest mechanical performance of the three materials considered because its yield strength is much higher than that of ABS or PLA materials. Polyester is expected to have the highest fracture resistance because its fracture toughness is much higher than that of ABS or PLA materials. Furthermore, because the fatigue strength of polyester is much higher than that of ABS or PLA, it is expected to achieve the highest fatigue strength. On the one hand, ABS density was estimated to achieve the best performance (lowest weight), but its price is the highest, reducing the economic benefits. Polyester, on the other hand, had the lowest price while having the highest density. On the one hand, the CO2 footprint of ABS was estimated to be high, with very high energy consumption when compared to other materials. PLA, on the other hand, has a low CO2 footprint and the lowest energy consumption when compared to other materials. It was decided that the most appropriate material would be polyester, which provides very high mechanical performance at a low cost and with a low environmental impact.

The iteratively solved matlab mathematical model predicted that irrigating 68 farms requires 37 flow control valves while irrigating 207 farms requires only 13 flow control valves. Increasing the number of operation hours is expected to help reduce the number of valves needed for the irrigation process. Unfortunately, increasing the number of operating hours is expected to result in higher electrical power consumption as well as more maintenance. Furthermore, increasing the amount of water required until the end of the growing season is expected to help shorten the growing season. Furthermore, increasing accumulated water consumption is expected to help extend the growing season. Furthermore, increasing the number of fields that can be irrigated using one valve per day is expected to help increase water flowrate. The number of valves has a significant impact on the flowrate of water.

The proposed system can be controlled by an Arduino system, which can be simulated using Tinker CAD software. It is expected that the software used will aid in remote control of the irrigation system. The control system was designed to be as simple as possible, which helps to reduce the system's initial cost.

This system is expected to consider two main operating scenarios, which are primarily affected by the moisture percentage in the soil. The following are some examples of these scenarios:

- If the soil moisture is less than 40%, the circuit is connected to operate the pumps (DC motors) to irrigate the Alfalfa in the farm. Figure 4.29 depicts the control circuit when the moisture content is less than 40%.
- If the soil moisture exceeds 40%, the circuit is disconnected to operate the pumps (DC motors), reducing water consumption. Figure 4.30 depicts the control circuit in the event that the moisture content exceeds 40%.

5.2. Recommendations

For the future scientific works, it is recommended to consider the following;

1. Investigating the effect of the flowrate on the pumping power losses to avoid excessive increase in the electrical power consumption leading to maximize the environmental and economic benefits. This can be achieved through applying a CFD study on the 3D modelled valve using ANSYS software.
2. Validating the proposed model by 3D printing the flow control valve and experimentally testing its performance for different scenarios.
3. Investigating the effect of changing the flow control valve category on the performance of the irrigation system.

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Appendix A: Properties for Polyester/E-glass

Composition detail (polymers and natural materials)

Polymer	25	-	35	%
Glass (fiber)	65	-	75	%

Price

Price	* 1.1	-	1.22	GBP/kg

Physical properties

Density	1.9e3	-	2.1e3	kg/m^3

Mechanical properties

Young's modulus	3.5e10	-	4.5e10	Pa
Yield strength (elastic limit)	6.9e8	-	8.28e8	Pa
Tensile strength	6.9e8	-	8.28e8	Pa
Elongation	0.02			strain
Elongation at yield	0.02			strain
Compressive modulus	3.5e10	-	4.5e10	Pa
Compressive strength	4.14e8	-	4.83e8	Pa
Flexural modulus	4.1e10	-	4.5e10	Pa
Flexural strength (modulus of rupture)	6.9e8	-	8.28e8	Pa
Shear modulus	* 1.4e10	-	1.8e10	Pa
Bulk modulus	* 4.07e10	-	4.27e10	Pa
Poisson's ratio	* 0.33	-	0.35	
Shape factor	15.4			
Hardness - Vickers	* 9.71e7	-	2.11e8	Pa
Hardness - Rockwell M	* 60	-	66	
Hardness - Rockwell R	* 95	-	105	
Fatigue strength at 10^7 cycles	4.14e8	-	4.97e8	Pa
Mechanical loss coefficient (tan delta)	* 0.00367	-	0.00444	

Impact & fracture properties

Fracture toughness	* 4.84e7	-	5.92e7	Pa.m^0.5
Impact strength, notched 23 °C	* 1.3e5	-	1.59e5	J/m^2

Electrical properties

Electrical resistivity	0.0909	-	0.1	ohm.m
Dielectric constant (relative permittivity)	4.55	-	5	
Dissipation factor (dielectric loss tangent)	* 0.00295	-	0.0134	
Dielectric strength (dielectric breakdown)	1.25e6	-	1.38e6	V/m

Optical properties

Transparency	Opaque

Magnetic properties

Magnetic type	Non-magnetic

Absorption & permeability

Water absorption @ 24 hrs	0.25	-	0.3	%

Durability

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Unacceptable
Strong alkalis	Unacceptable
Organic solvents	Unacceptable
Oxidation at 500C	Unacceptable
UV radiation (sunlight)	Good
Flammability	Highly flammable

Primary production energy, CO2 and water

Embodied energy, primary production	* 7.64e7	-	8.43e7	J/kg
CO2 footprint, primary production	* 4.16	-	4.59	kg/kg
Water usage	* 0.254	-	0.281	m^3/kg

Appendix B: Properties for ABS

Composition detail (polymers and natural materials)

Polymer	100			%

Price

Price	* 2.47	-	2.72	GBP/kg

Physical properties

Density	* 1.06e3	-	1.09e3	kg/m^3

Mechanical properties

Young's modulus	1.18e9	-	1.47e9	Pa
Yield strength (elastic limit)	2.85e7	-	3.55e7	Pa
Tensile strength	3.78e7	-	4.62e7	Pa
Elongation	0.609	-	0.876	strain
Elongation at yield	0.0638	-	0.121	strain
Compressive modulus	* 1.26e9	-	1.39e9	Pa
Compressive strength	* 4.79e7	-	5.29e7	Pa
Flexural modulus	1.23e9	-	1.47e9	Pa
Flexural strength (modulus of rupture)	4.95e7	-	6.05e7	Pa
Shear modulus	* 4.57e8	-	4.81e8	Pa
Shear strength	* 2.27e7	-	2.77e7	Pa
Bulk modulus	* 2.38e9	-	2.63e9	Pa
Poisson's ratio	* 0.396	-	0.412	
Shape factor	4.8			
Hardness - Vickers	* 8.94e7	-	9.9e7	Pa
Hardness - Rockwell M	* 90.2	-	99.7	
Hardness - Rockwell R	* 90.2	-	99.7	
Hardness - Brinell	5.87e7	-	7.33e7	Pa
Hardness - Shore D	* 73.9	-	76.9	
Fatigue strength at 10^7 cycles	* 1.6e7	-	1.76e7	Pa
Mechanical loss coefficient (tan delta)	* 0.0216	-	0.0239	

Impact & fracture properties

Fracture toughness	* 3.24e6	-	3.58e6	Pa.m^0.5
Impact strength, notched 23 °C	5.78e4	-	1.12e5	J/m^2
Impact strength, notched -30 °C	6.3e3	-	1.37e4	J/m^2
Impact strength, unnotched 23 °C	5.9e5	-	6e5	J/m^2
Impact strength, unnotched -30 °C	5.9e5	-	6e5	J/m^2

Electrical properties

Electrical resistivity	2e10	-	5e11	ohm.
Dielectric constant (relative permittivity)	* 7.31	-	10.3	
Dissipation factor (dielectric loss tangent)	* 0.0372	-	0.0982	
Dielectric strength (dielectric breakdown)	* 1.81e7	-	3.09e7	V/m
Comparative tracking index	600			V

Optical properties

Transparency	Opaque

Magnetic properties

Magnetic type	Non-magnetic

Absorption & permeability

Water absorption @ 24 hrs	0.68	-	1.1	%
Water absorption @ sat	3	-	4	%
Humidity absorption @ sat	1.1	-	1.4	%

Processing properties

Polymer injection molding	Excellent			
Polymer extrusion	Excellent			
Polymer thermoforming	Limited use			
Linear mold shrinkage	0.3	-	1	%
Melt temperature	191	-	271	°C
Molding pressure range	5.5e7	-	1.72e8	Pa

Appendix C: Properties for PLA

Composition detail (polymers and natural materials)

Polymer	60			%
Impact modifier	10			%
Calcium carbonate (powder)	30			%

Price

Price	* 1.57	-	1.75	GBP/kg

Physical properties

Density	1.39e3	-	1.41e3	kg/m^3

Mechanical properties

Young's modulus	* 4.04e9	-	4.24e9	Pa
Yield strength (elastic limit)	3.12e7	-	3.28e7	Pa
Tensile strength	* 2.4e7	-	2.53e7	Pa
Elongation	* 0.0567	-	0.061	strain
Elongation at yield	0.0289	-	0.0311	strain
Compressive modulus	* 4.04e9	-	4.24e9	Pa
Compressive strength	3.75e7	-	3.94e7	Pa
Flexural modulus	4.04e9	-	4.24e9	Pa
Flexural strength (modulus of rupture)	4.39e7	-	4.61e7	Pa
Shear modulus	* 1.46e9	-	1.51e9	Pa
Bulk modulus	* 5.95e9	-	6.58e9	Pa
Poisson's ratio	* 0.38	-	0.4	
Shape factor	14			
Hardness - Vickers	* 8.83e7	-	9.81e7	Pa
Hardness - Rockwell M	* 41	-	43	
Hardness - Rockwell R	* 25	-	27	
Hardness - Shore D	* 79	-	83	
Fatigue strength at 10^7 cycles	* 1.66e7	-	1.69e7	Pa
Mechanical loss coefficient (tan delta)	* 0.0858	-	0.0887	

Impact & fracture properties

Fracture toughness	* 1.29e6	-	1.36e6	Pa.m^0.5
Impact strength, notched 23 °C	7.6e3	-	8.4e3	J/m^2
Impact strength, unnotched 23 °C	7.6e4	-	8.4e4	J/m^2

Electrical properties

Electrical resistivity	* 2.2e9	-	4.2e9	ohm.m
Dielectric constant (relative permittivity)	* 4.55	-	4.74	
Dissipation factor (dielectric loss tangent)	* 0.00663	-	0.00802	
Dielectric strength (dielectric breakdown)	* 1.39e7	-	1.44e7	V/m

Optical properties

Refractive index	* 1.44	-	1.46	
Transparency	Opaque			

Magnetic properties

Magnetic type	Non-magnetic			

Absorption & permeability

Water absorption @ 24 hrs	* 0.12	-	0.13	%
Water absorption @ sat	* 0.48	-	0.53	%
Humidity absorption @ sat	* 0.14	-	0.16	%
Water vapor transmission	8.22e-11	-	1.05e-10	kg.m/m^2.s
Permeability (O2)	1.26e-18	-	6.05e-18	m^2/s.Pa

Processing properties

Polymer injection molding	Acceptable			
Polymer extrusion	Limited use			
Polymer thermoforming	Limited use			
Linear mold shrinkage	* 0.3	-	0.4	%
Melt temperature	170	-	200	°C
Mold temperature	80	-	105	°C
Molding pressure range	5.5e7	-	1.03e8	Pa

Appendix D: Matlab code

```
Clear
Clc
%%%Alfalfa%%%%%%%%%
%this code to calculate the number of valves are required
to irrigate the
%farm with area A (m^2) with (NF) number of fields.
Q=1600; % mm/ growing period ( maximum requirements
according to FAO)
A =10000 % AREA
top(1)= 10% the time of operation (hours)
Af=4% area of field (m^2)
NF= A/Af; %number of fields
VQ=Af*Q/100; %the volume required for one field (m^3)
QT= VQ*NF; % the total volume for irrigate the crop during
the period
% according to FAO the growing period for Alfalfa was
estimated from 5 march
%to 13 October, so its  222 days
pp =220; % the period of growing
f=0.1;%the flow rate of the valve ( m^3/min)
fd=VQ/pp % The daily  water requirement for irrigate one
field
t=fd/f% the time for irrigate one field (min)
nof(1)=ceil(top(1)*60/t)% number of fields can be irrigated
by
%one valve during operation time operation
nv(1)=ceil(NF/nof(1)); % the number of valves are available
q(1)=fd%water requirements per irrigate
tq(1)=q(1)% accumulative water consumption
rsq(1)=VQ-tq(1)

%effect increasing number of valves 10%
for i=2:10
nv(i)=ceil(nv(i-1)+0.1*nv(i-1))
nof(i)=ceil(NF/nv(i))
top(i)=nof(i)*t/60
q(i)=nv(i)*f*60*top(i)%water requirements per irrigate
end
for j=2:pp
tq(j)=q(1)*j% accumulative water consumption
rsq(j)=VQ-tq(j)% the rest required water up to end growing
```

```
end
%%%%%%%%%%
figure
plot(nv,nof,'b-s')
xlabel('Number of Valves')
ylabel('Number of fields')
grid on
grid minor
%%%%%%%%%%%%%%%%
figure
plot(nv,top,'r-*')
xlabel('Number of Valves')
ylabel('Operation time(hours)')
grid on
grid minor

%%%%%%%%%
figure
plot(1:pp,rsq,'g-*')
xlabel('period of growing( days)')
ylabel(' water required up to end growing (m^3)')
grid on
grid minor
%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%
figure
plot(1:pp,tq,'b-*')
xlabel('period of growing( days)')
ylabel('accumulative water consumption (m^3)')
grid on
grid minor
%%%%%%%%%%%%%%%%%%
% this code to investigate the effect of flow rate of valve
on where the min
% flow rate was assumed 0.2 GPM (0.0007571 m^3/min) and the
maximum is
%30 GPM (0.1135623 m^3/min)for similar
% valves in market
s=100; %number of solution steps
fmin= 0.007571; % the minimum flow rate ( m^3/min)
fmax=0.1135623;% the maximum flow rate
df=(fmax-fmin)/s% flow rate incremental
fc(1)=fmin% initial flowrate
```

```
nofc(1)=ceil(top(1)*60/(fd/fc(1)))% number of fields can be
irrigated by
%initial flowrate
nvc(1)=ceil(NF/nofc(1))
for i=2:s
 fc(i)= fc(i-1)+df
 nofc(i)=ceil(top(1)*60/(fd/fc(i)))% number of fields can
be irrigated by
 %one valve during operation time operation
nvc(i)=ceil(NF/nofc(i)); % the number of valves are
required
end

figure
plot(fc,nofc,'b-^')
xlabel('flow rate (m^3/min)')
ylabel('Number of fields/one valve/day')
grid on
grid minor
%%%%%%%%%%%%%%%%
figure
plot(fc,nvc,'b-s')
xlabel('flow rate (m^3/min)')
ylabel('Number of Valves)')
grid on
grid minor
%%%%%%
```

Appendix E: Tinker CAD code

```
#include<LiquidCrystal.h>
LiquidCrystal lcd(12,11,5,4,3,2);
#define moisturepin A0
#define signalpin 6
int moisturevalue = 0;
void setup()
{
  pinMode(moisturepin,INPUT);
  pinMode(signalpin,OUTPUT);
  lcd.begin(16,2);
}
void loop()
{
  moisturevalue = analogRead(moisturepin);
   if(moisturevalue <= 400)
 {
   digitalWrite(signalpin,HIGH);
    lcd.setCursor(0,1);
    lcd.print("Motor is On ");
  }
  else
  {
    digitalWrite(signalpin,LOW);
    lcd.setCursor(0,1);
    lcd.print("Motor is Off ");
  }
```

```
  lcd.setCursor(0,0);
  lcd.print("Moisture Value....");
  lcd.setCursor(13,1);
  lcd.print(moisturevalue);
}
```