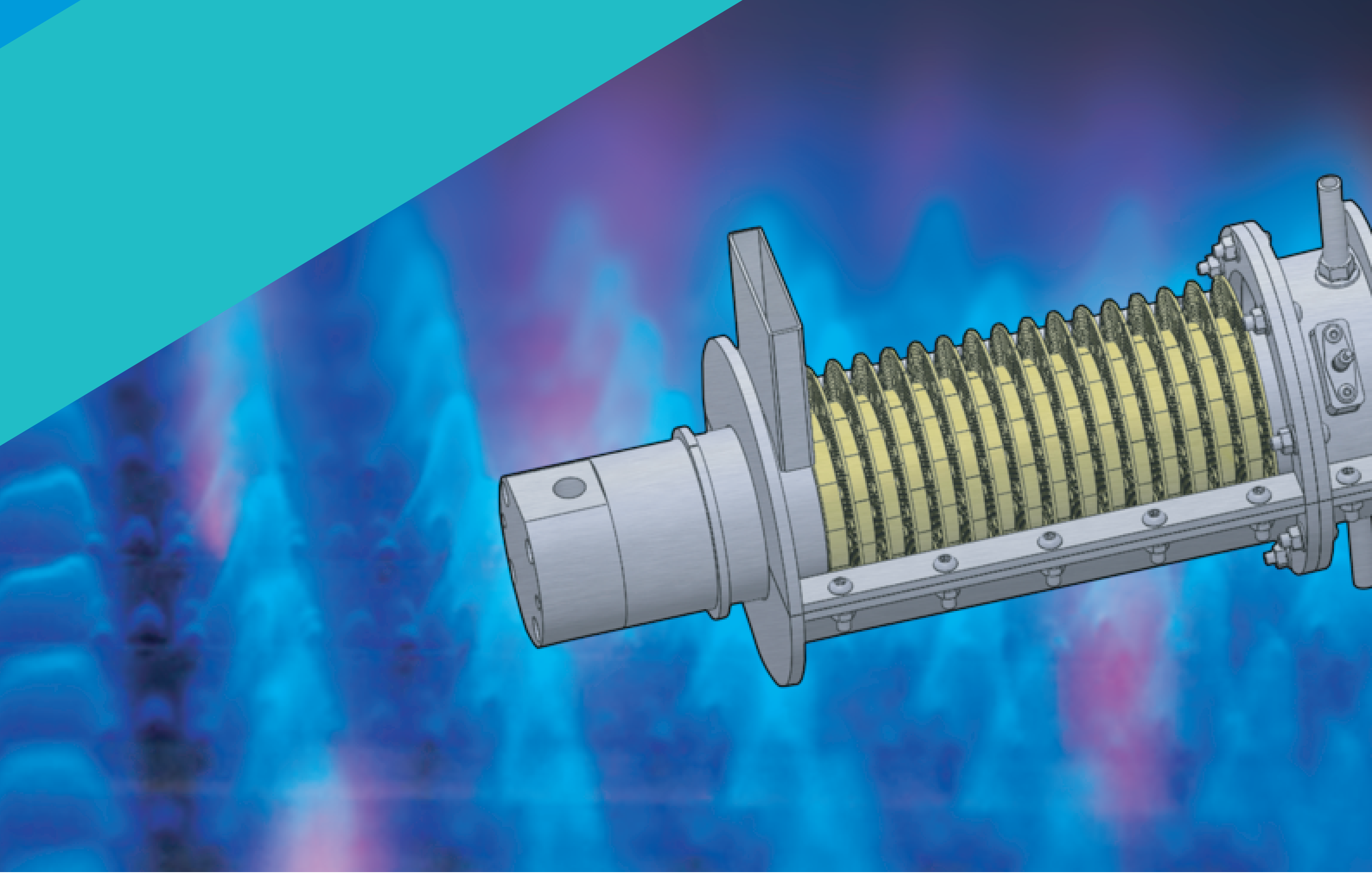
Professorship for Polymer Engineering

Gas fuelled injection moulding heater

Thermal & Constructional redesign



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Colophon

Title:	Gas Fuelled Injection Moulding Heater: Thermal & Constructional Re-design
Publication number:	LKT-RE-105207-1912
Publication date:	December 2019
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Funded by:	Green PAC
In collaboration with:	3Force
Photography:	All photography by the authors

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Summary

Within the context of the research programme "Koenst), a natural gas (methane) fuelled heater (Prototype I[1]) for injection moulding has been developed. When tested, the first prototype of this natural gas fuelled heater showed cracks at some specific spots, especially certain corners inside the hull. Studies showed that these cracks were caused by thermal stress components. A downscaled and re-designed prototype was produced (Prototype II), built for further validation under the appropriate test conditions. Unlike the first prototype, the re-designed prototype showed no cracks.

Even though most of the problems were solved in this prototype, it was expected that the efficiency of the heater could be further improved. Aim of the study presented here was to improve the gas fuelled heater through a *thermal and constructional re-design*. The study has been carried out as part of the research programme "Ontwerpgereedschappen voor Extrusie" (Designtools for Extrusion).

Thermal re-design

The objective of the thermal re-design was to increase the thermal efficiency of the gas heater by some 20% (10% points), through an overall re-design of the device.

Starting point of the study was an Ansys-CFX simulation of "Protypte II". Based on this simulation, a thermal efficiency of 53.6% was calculated.

An evaluation of the heat transferring principles used in this preliminary design indicated that applying alternative principles of heat transfer could lead to an increased efficiency. A new concept was developed ("Full Disc" concept). This design includes a series of discs (increasing the heat extraction area) mounted on the barrel (increasing heat transfer). Additionally, the discs contain holes (inducing turbulence). Through the application of these new heat extraction and heat transfer principles, it was possible to raise the efficiency of the heater substantially. From Ansys-CFX simulations it could be concluded that the thermal efficiency was increased to 65.0%, an improvement of about 21%, i.e. 11 % points as compared to Prototype II.

Based on these findings, Re-design final concept was developed, solving various design issues with regard to manufacturing and assembly. This final concept featured segmented discs with staggered holes for increased turbulence ("Segmented Discs" concept). Again simulations were carried out with Ansys-CFX showing that the overall energy efficiency of the heater could be increased to 66.6%, thus meeting the pre-set design goal to raise the thermal efficiency by 20%.

[1] During the several stages of this research project various gas fuelled heater designs have been developed, and three prototypes have been built. For reference, please refer to the section "Overview of Gas Fuelled Heater Prototypes".

Constructional Re-design

Based on the findings of the *thermal* re-design, a *constructional* re-design was initiated, resulting in a fully specified and detailed design of the heater. On this basis, a new prototype (“Type III”) was produced. This new prototype was subjected to a series of preliminary tests to obtain information on ease of assembly and energy efficiency.

Next a detailed design was created in which production and assembly were taken into account as well. The production of the prototype heater and the test setup were executed by several parties, including 3Force and Hoekman-Roestvaststaal. It was found that the reduced complexity of the parts in the heater resulted in easier assembly.

Although the test set up was far from ideal, it can be carefully concluded that the efficiency of the heater came in the range of 61.5% which is remarkably in line with the simulation results.

Acknowledgement

This project was carried out in close cooperation with several parties. The authors wish to thank:

- Arendt Jan Smit from 3Force, for his invaluable advice on the re-design and his help during the improvised testing of the equipment at the 3Force laboratories.
- Gerrit Hoekman from 3Force, for his advice and practical recommendations to further simplify the design to enable easier production and assembly, and his assistance in the actual making of the prototype
- Matthias Bittern and colleges from WEMA GmbH, for their support and for making providing background information on current market developments
- Christian Hummel, for his expert support during the Ansys-CFX simulations, as well as for his input during design sessions
- Jakob Buist from the Professorship for Polymer Engineer at Windesheim, for his enthusiastic, stimulating and tireless support on technical, theoretical and personal issues.

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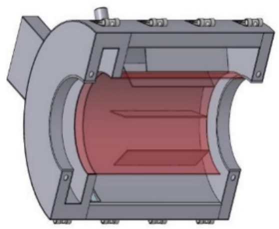
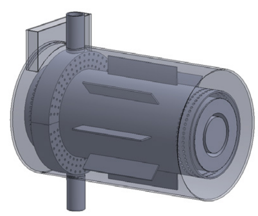
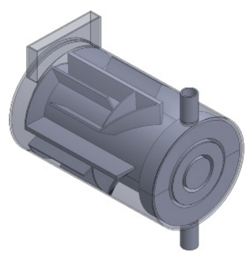
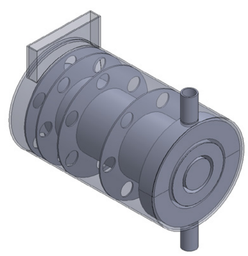
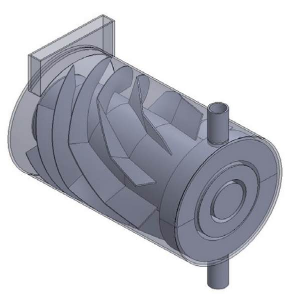
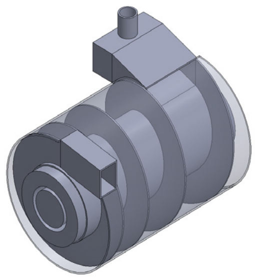
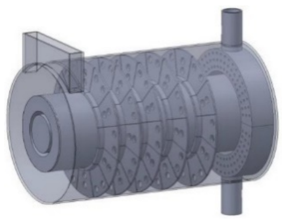
Overview of Gas Fuelled Heater Prototypes

During the several stages of this research project various gas fuelled heater designs have been developed, and three prototypes have been built. For reference, Table 0-1 (below) provides an overview of the gas fuelled heater designs and prototypes included in this research report.

Prototype I	 

Prototype II	 

Re-design concept 1 ("Labyrinth")	
Re-design concept 2 ("Full Discs")	
Re-design concept 3 ("Twist")	

Re-design concept 4 ("Spiral")	
Re-design final concept ("Segmented discs")	

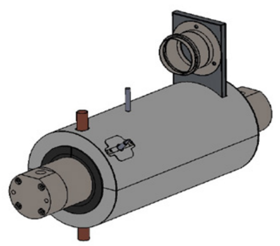
Prototype III	 

Table 0-1: Reference table of gas fuelled heater designs and prototypes discussed in this report.

1. Project introduction

1.1. Project context

In the process of injection moulding[2], molten thermoplastic material is pressed into a mould by means of an extrusion screw. The heat necessary to transform the input solid thermoplastic granulate into the liquid phase is partially produced by friction between granulate, the extrusion screw and the confining wall. In many cases, additional heat is required to obtain optimal viscosity of the molten plastics. Traditionally, this heat is produced by electric heating coils, wrapped around the extruder.

1.1.1. Earlier developments: reducing thermal stress and cracks

As an alternative to electric heating, natural gas fuelled heating systems have been developed, e.g. by Wortberg an Schroer in “Novel Barrel Heating with Natural Gas” [1]. Based on this system, further developments within the context of the ”Koenst” project have led to the natural gas fuelled heater (“Prototype I”) shown in Figure 1-1. The system consists of a cylindrical hull, which is positioned around the extruder screw.

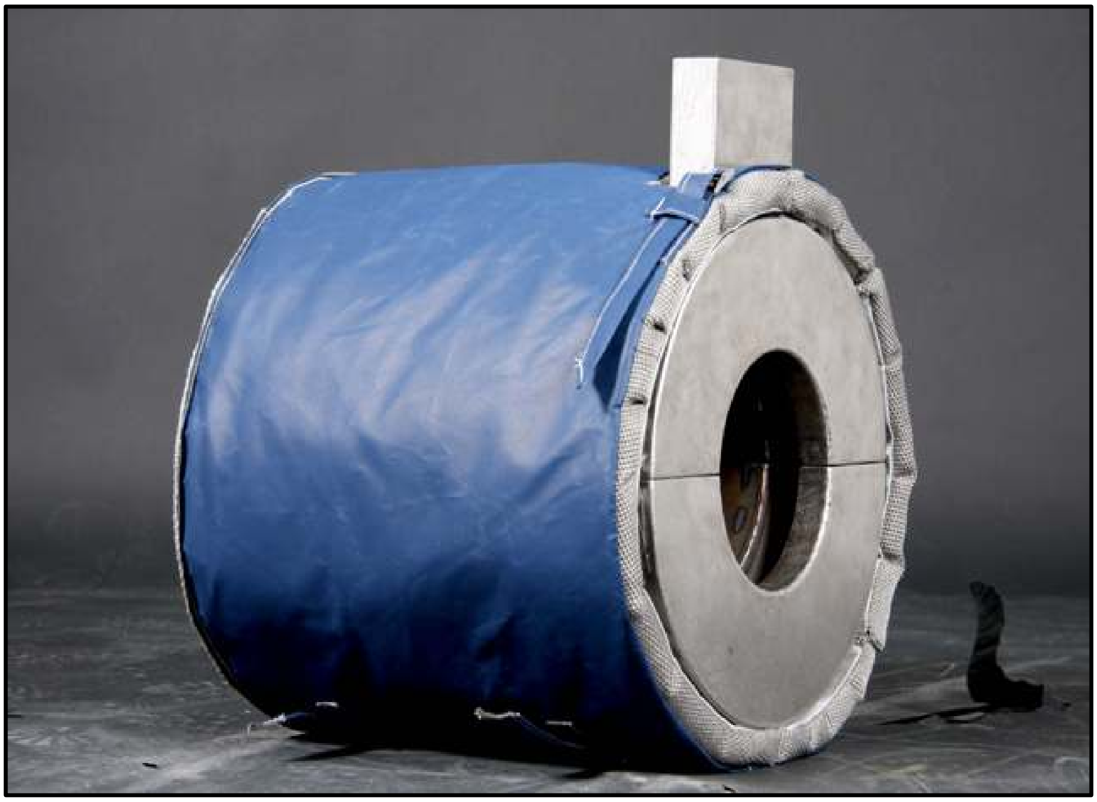


Figure 1-1: Natural gas fuelled heater (Prototype I).

Figure 1-2 shows a cross section of the heater. The hot combustion gasses are led in upstream direction over a radiation plate and then flow in downstream direction along the extrusion wall. Finally,

[2] The focus of this report is on the application of a gas fuelled heater for injection moulding, but application in polymer extrusion processes is basically identical.

the cooled combustion gasses are discharged through the exhaust. During this whole process, heat is transferred from the combustion gasses to the extruder and thermoplastics inside the extruder.

Prototypes of the system have been field tested under real production conditions for injection moulding by WEMA GmbH and 3Force. The system proofed to be effective and relatively energy efficient. However, after dismantling the heater, cracks were found in some specific areas, especially certain corners, inside the hull. It has been suggested that these cracks were caused by thermal stress concentrations in the construction.

Figure 1-2: Cross section of the heater (Prototype I)

Following the findings of the duration tests with the original heater, a downscaled and re-designed prototype (“Prototype II”) was developed for further testing (see Figure 1-3). Unlike the original Prototype I, the re-Prototype II did not show any cracks after completion of the duration tests.

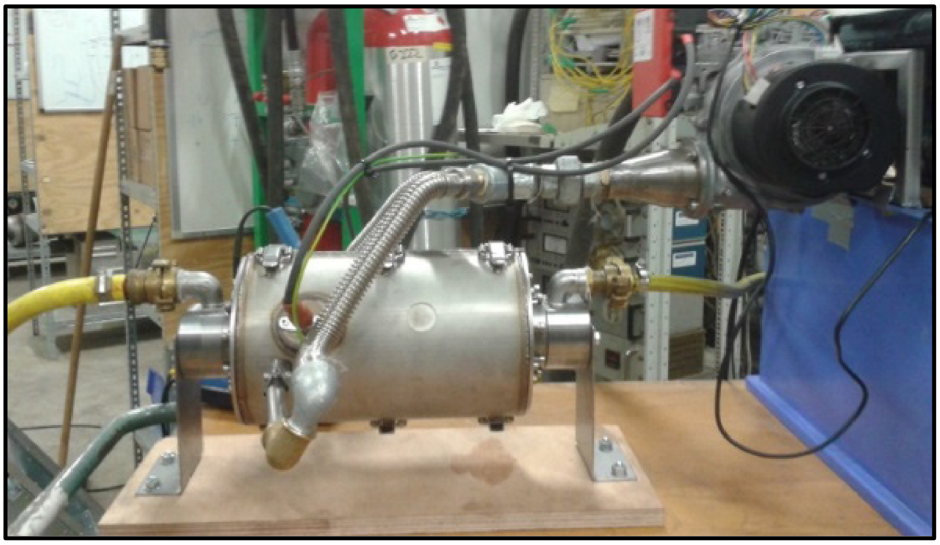


Figure 1-3: Prototype II under testing conditions.

1.1.2. This study: improving thermal and constructional properties

Once the problems with the thermal stresses in Prototype I were solved by Prototype II, attention shifted towards optimisation with regard to *thermal and constructional re-design*.
The need for a *thermal re-design* came up during the test phase testing of Prototype II, of which the working principle is shown in Figure 1-4: Working principle of Prototypes I and II. The efficiency of the applied heat transferring principles in both Prototype I and II (a radiation plate heating the back flow and convection from combustion gasses directly to the barrel) was questioned.

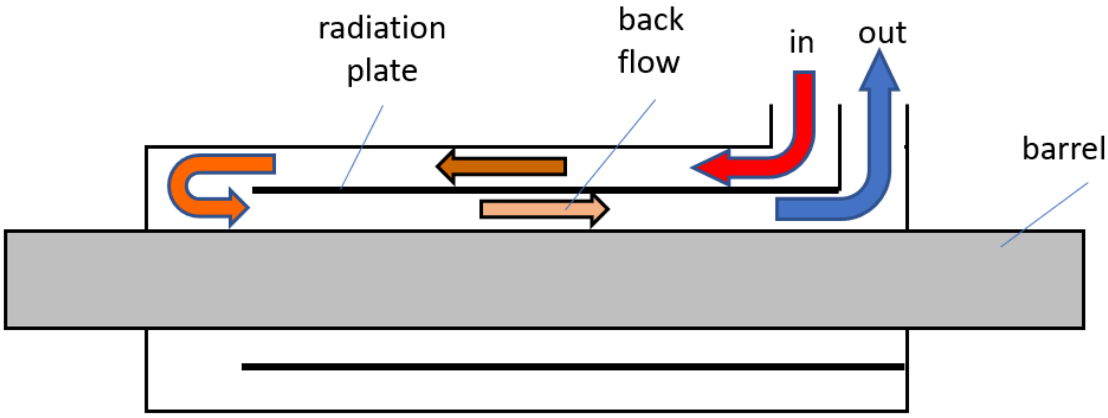


Figure 1-4: Working principle of Prototypes I and II.

It was suggested that the design of the heat transferring concept could be adjusted to improve its efficiency. By increasing the total area for heat transfer using so called "fins", it was believed that heat could be conveyed more efficiently from gas to barrel.
A complete *constructional re-design* of Prototype II became the objective of the second part of this study. During production and testing of Prototype II constructional issues came to the surface. Production and assembly of the proofed to be labour intensive and difficult. A need was identified for further optimisation with regard to construction and assembly, insulation and sealing.

1.2. Objectives and approach

Following the identified need for thermal and constructional improvements, the objectives below were formulated:

1.2.1. Thermal re-design

The objectives and approach for the thermal re-design of the heater were formulated as follows:

Objective:	-	to improve the thermal efficiency of the gas fuelled heater
Approach:	-	to evaluate the heat transferring principles of the preliminary design
	-	to find alternative principles for improved heat transfer
	-	to compare heat transferring efficiency using Ansys CFX simulations

1.2.2. Constructional re-design

The objectives and approach for the constructional re-design of the heater are formulated as follows:

Objective:	-	to implement the findings of thermal re-design, and improve the constructional efficiency of the overall design
Approach:	-	to evaluate the constructional details of earlier heater models
	-	to make a new (detailed) design for the heater, based on the findings
	-	to produce a new prototype (“Prototype III”)

2. . Thermal re-design

2.1. Introduction

This report is a thermal re-design of a gas fuelled barrel heater as an alternative heating device for injection moulding machines. Most commonly injection moulding heating equipment is based on electric heating elements. A heating device using natural gas (methane) offers a few interesting options. Not only does it open up the possibility to use renewable fuel sources (e.g. biogas), but it also enables the injection moulding machines to be placed in locations with a limited electricity supply.

In this chapter the thermal re-design of the Prototype II gas fuelled burner is addressed. This burner was previously simulated and tested, but it was noted that there was still room to improve the efficiency. In the following paragraphs this thermal design process is presented.

2.1.1. Preliminary design Prototype II

The preliminary design of the burner is shown Figure 2-1.The burner consists of a shell which is placed around the barrel of an injection moulding machine. A premixed natural gas and air mixture is led into the burner through vertically placed round tubes positioned in the top and bottom. The mixture is ignited at the front of the 'burner' (the disc with the grid of holes) where it combusts and expands.

Figure 2-2 shows the flow of the gas through the heater. The blue, green and yellow lines represent the flow lines of the gas, as calculated by the simulation. The flue gas is guided by the 'Radiation Plate' (the finned pipe) where it releases its energy. As a consequence, the radiation plate becomes red hot. When the flue gas reaches the end of the burner, it goes through the holes at the end of the radiation plate where it comes into contact with the barrel of the injection moulding machine and releases more energy. Here, the heat from the glowing radiation plate is also transferred to the barrel by means of thermal radiation (hence the name). A portion of the energy radiated by the plate is also picked up by the (now cooler) flue gasses, which exit the burner at the left side through the exhaust. This process of "reheating" the gasses possibly reduces the efficiency of the device.

2.1.2. Simulations

In this report, three different versions of the burner have been simulated using Ansys CFX: Prototype II design, the first version of the re-design ("Full Disc") and the final concept ("segmented Disc"). All three versions of the heater were simulated using the same basic dimensions, flows and heat input. The simulations were carried out to obtain the necessary data to calculate the thermal efficiency of the three models. The polymer flow was simulated using readily available input data for thermal oil. For further details on the simulation input and output see table 2.1.

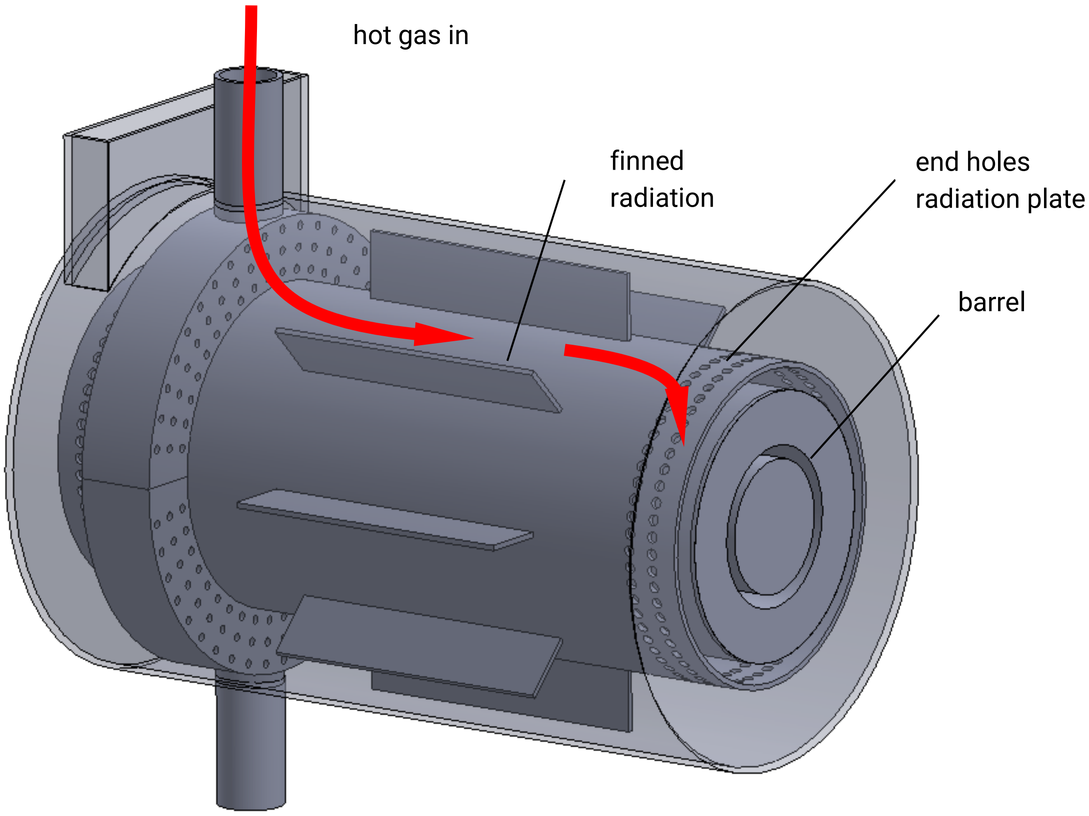


Figure 2-1: Prototype II heater: design.

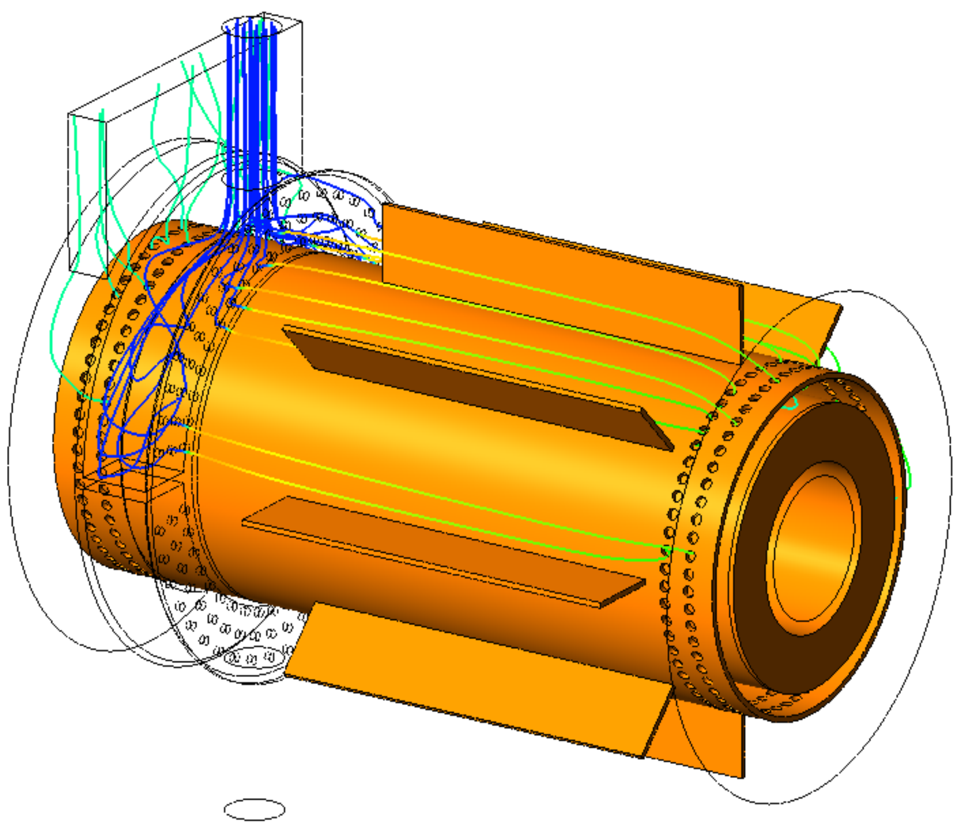


Figure 2-2: Prototype II heater: gas flow.

2.1.3. Temperature distribution and efficiency

The prototype II burner was simulated using Ansys CFX. The thermal efficiency was calculated based on the rise of temperature in the polymer flow. Figure 2-3 shows the temperature distribution in the heater.

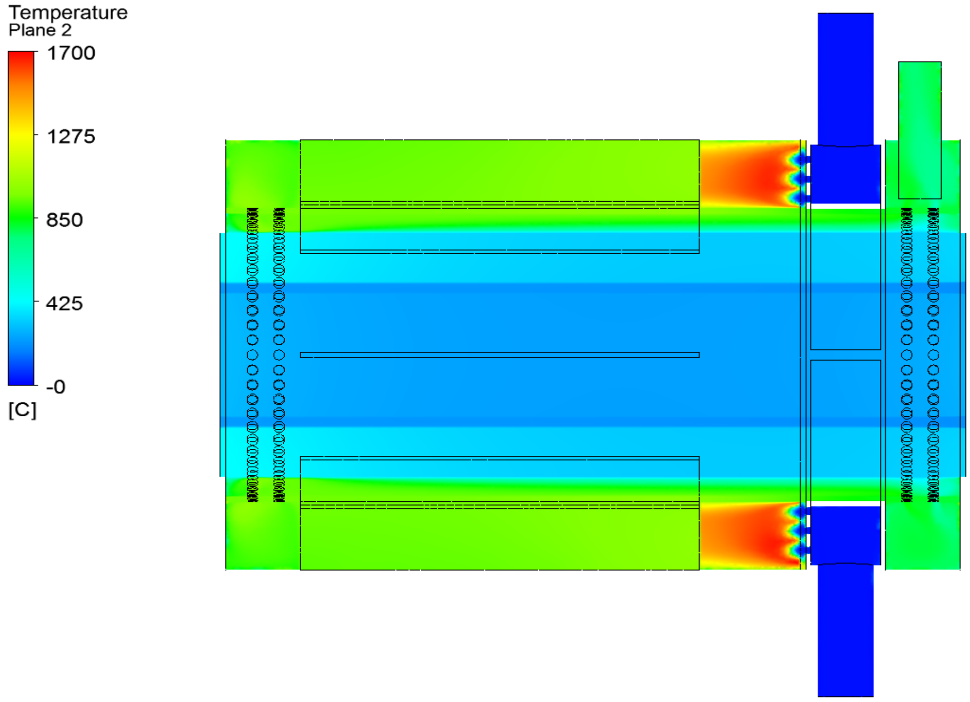


Figure 2-3: Prototype II heater: temperature of gas flow.

The polymer enters the barrel at a mass flow rate of 0.039 kg/s with a temperature of 200 °C. The amount of
energy entering the burner is fixed by the amount of the gas and air mixture. This is set at 5 kW. The thermal efficiency η is calculated according to formulas (2-1), (2-2) and (2-3). It is the ration between useful energy out (heated polymer flow) and energy in (combusted gas-mixture). For details of the values and constants used see table 2-1.

The overall thermal efficiency η is calculated as follows:

$$\boldsymbol{\eta = \frac{\dot{Q}_{p,out}}{\dot{Q}_{g,in}} * 100\%} \tag{2-1}$$

η	:	$thermal\ efficiency$	$[\%]$
$\dot{Q}_{p,out}$	:	$heat\ content\ of\ polymer\ (output)\ per\ time\ unit$	$[kW]$
$\dot{Q}_{g,in}$	:	$heat\ content\ of\ gas\ mixture\ (input)\ per\ time\ unit$	$[kW]$

Where $\dot{Q}_{g,in}$ is:

$$\boldsymbol{\dot{Q}_{g,in} = \dot{m}_{g,in} \cdot H_{0,CH_4} \cdot \chi_{CH_4}} \tag{2-2}$$

$\dot{Q}_{g,in}$	:	$heat\ content\ of\ gas\ mixture\ \ (input)\ per\ time\ unit$	$[kW]$
$\dot{m}_{g,in}$	:	$mass\ flow\ of\ gas\ mixture\ (input)$	$[kg/s]$
H_{0,CH_4}	:	$lower\ heating\ value\ of\ CH_4$	$[kJ/kg]$
χ_{CH_4}	:	$CH_4\ content\ of\ gas\ mixture$	$[kg/kg]$

And where $\dot{Q}_{p,out}$ is:

$$\boldsymbol{\dot{Q}_{p,out} = \dot{m}_{p,out} \cdot c_{p,p} \cdot (T_{p,out} - T_{p,in})} \tag{2-3}$$

$\dot{Q}_{p,out}$	:	$heat\ content\ of\ polymer (output)\ per\ time\ unit$	$[kW]$
$\dot{m}_{p,out}$	:	$mass\ flow\ of\ polymer\ (output)$	$[kg]$
$c_{p,p}$	:	$specific\ heat\ content\ of\ polymer$	$[KJ/kgK]$
$T_{p,out}$	:	$temperature\ of\ polymer\ (out)$	$[°C]$
$T_{p,in}$	:	$temperature\ of\ polymer\ (in)$	$[°C]$

In the Protype II design, the polymer flow exiting the barrel had a temperature of 233 °C. The temperature of the flue gasses exiting the burner was 782 °C. Together with the mass flow and the amount of energy entering the system an efficiency of 53.6 % was calculated.

2.1.4. Pressure drop

Another important factor in the design of a burner is the pressure drop in the flue gas it introduces. For the original design this is depicted in Figure 2-4. The total pressure drop in the burner is about 79 Pa. According to information of project partner 3Force, this value is in accordance with what can be expected based on industry experience, where as a rule of thumb the overall pressure drop should not exceed 300 Pa. It was therefore concluded that the calculated value of 79 Pa is acceptable.

In the following paragraphs a comparison will be made with the design after thermal optimisation.

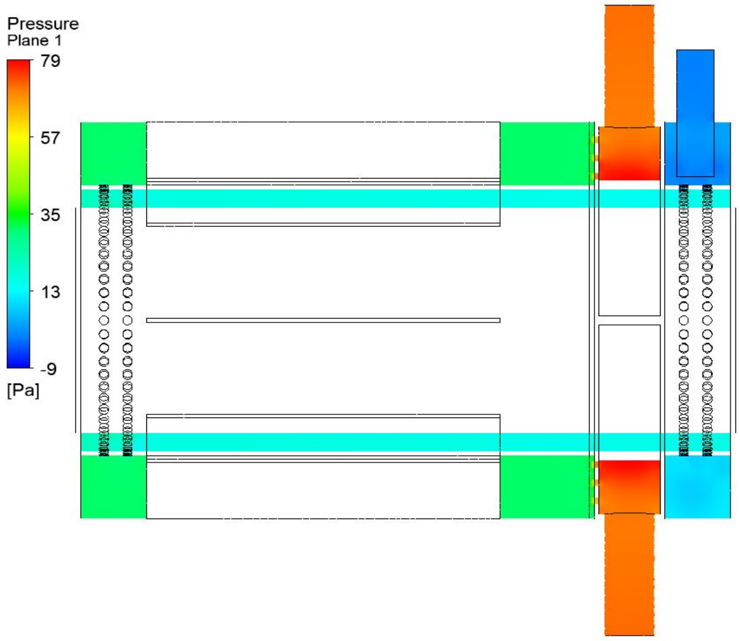


Figure 2-4: Prototype II heater: pressure distribution.

2.2. Analytical phase

In order to improve the efficiency of the burner, the energy transferring principles of the device need to be understood. To accomplish this, a mind map was developed.

2.2.1. Mind map/Work structure

A mind map of the working principles is shown in Figure 2-5 and presents an overview of options to improve the thermal efficiency.

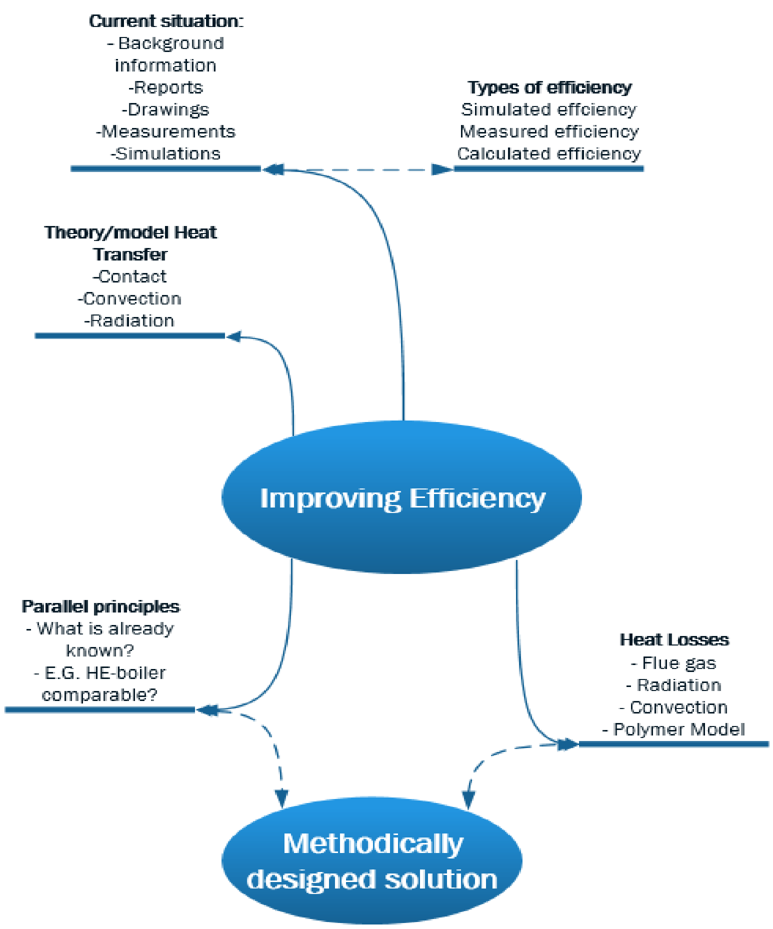


Figure 2-5: Mind map of working principles for improvement of thermal efficiency.

2.2.2. Design goal

Target was to improve the thermal efficiency with 20% (10%-point) compared to Prototype II, which would lead to an increased efficiency of 53.6% * 120% = 64,3%. Note: this (rather arbitrary) goal was set in agreement with the prime stakeholders. To reach this goal, the operating principles of the burner were investigated as presented in the next paragraph.

2.2.3. Operation principles

The purpose of the burner is to heat the barrel of an injection moulder. A method had to be developed to extract the heat from combustion (and thus the flue gas) and direct it towards the barrel where it is absorbed. The operating principles can thus be divided in two categories: Heat extraction and heat transfer. These categories are addressed on the next page.

2.2.4. Heat extraction

The following ideas for improved heat extraction were identified:

- Enlarged contact area (e.g. fins)
- Increased contact time (e.g. labyrinth)
- Enlarged surface area (e.g. rough surface)
- Turbulence (e.g. obstructions)
- Infrared radiation (e.g. reflective plate)

Enlarged contact area

To extract heat from a flowing gas to a solid object (the barrel or heat transfer device) a number of solutions exist. Because heat extraction depends (among other things) on surface area, the first solution that stands out is to enlarge the contact area with the flue gasses. A method to enlarge the contact area is to add extra surfaces to the flow area. An example of this principle is ***fins***, Figure 2-6.

Figure 2-6: Heat extraction principle: fins.

Increased contact time

Another method is to elongate the path that the flue gasses have to travel to reach the exit of the burner, is by applying some sort of **labyrinth, see** Figure 2-7.

Figure 2-7: Heat extraction principle: labyrinth.

Enlarged surface area
Increasing the surface roughness (for instance by anodization of a metal, see Figure 2-8) will ***enlarge the* surface area** while not taking up extra space.

Figure 2-8: heat extraction principle: rough surface.

Turbulence
Heat extraction can also be improved by maintaining a ***turbulent gas flow*** around the surface. This principle is presented in Figure 2-9.

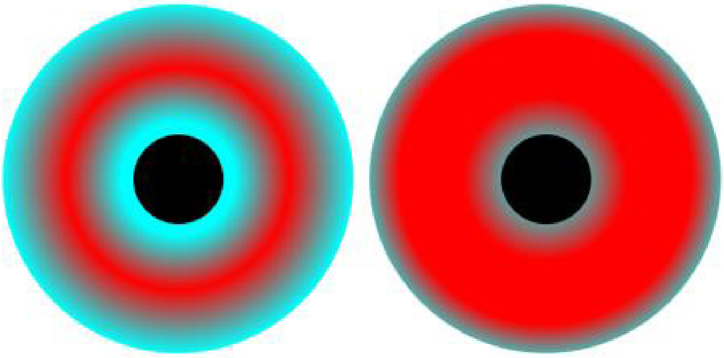


Figure 2-9: Heat extraction: temperature distribution non-turbulent (l), turbulent(r).

Turbulence in a flowing gas means that while the velocity of the gas at a contact surface is virtually zero, the gas is constantly mixed. A non-turbulent (i.e. laminar) flow can be converted into a turbulent flow by introducing obstructing objects. The flowlines will be forced to change direction, which promotes a "mixing" effect. This ensures that the temperature distribution in the gas flow becomes more homogenous. In a situation where hot gas is surrounded by relatively cool solids this means that in a turbulent situation the gas is hotter around the contact surface than in a non-turbulent situation, where the gas has a temperature peak in the centre with little heat transfer. Figure 2-9 provides a schematic representation of this working principle.

To maintain this turbulence in a flow of gas, obstructing objects have to be placed in the flow area. The more the direction of a gas flow is diverted, the more turbulence occurs. The aforementioned fins are a method to ensure a mixing effect in the gas and maintain turbulence. Other obstructions like walls perpendicular to the gas flow achieve a colliding effect which also improves turbulence and thus heat transfer.

Infrared radiation
Another method to improve the extraction of heat is to make use of the **infrared radiation** as emitted by the hot gas itself. A highly reflective metal surface will reject this heat and not absorb it whereas a black and mat surface will absorb.

2.2.5. Heat transfer

The second operating principle to be discussed is improved heat transfer. The heat has to be extracted from the gas flow and transferred to the barrel of the injection moulding machine. Because the barrel cannot be modified in any way (as is it required that the burner is a universal 'module', adaptable to any kind of injection moulding machine), a mechanism has to be designed to transfer the heat from the 'extractor' to the barrel. Clamping a piece of metal onto another piece of metal will not transfer heat optimally because of variations in the surfaces and dimensional tolerances in manufacturing. There are roughly two ways to counter this:

- Series of contact elements (e.g. labyrinth)
- Soft element (e.g. lead, copper, …)

Series of contact elements
One way is the use of a great number of small contact elements (Figure 2-10). This way a perfectly smooth surface and a tight tolerance is not required because of the vast number of small contact areas which will compensate for the smoothness. An advantage of this method is that it is not very complicated to fabricate and assemble. A disadvantage is that the heat transfer will always be less than that of a perfect solid contact (e.g. a fin welded to the barrel). However, modification of or welding on the barrel is not allowed.

Soft element

Another way is to put a soft and ductile medium in between the surfaces, for instance a sheet or strip of some kind of soft metal such as lead (Figure 2-11). The compression of this metal sheet will smooth out the surface roughness and ensure a nearly perfect contact and thus heat transfer. The low melting point of soft ductile metals however makes it an unsuitable option as the surface temperatures in the burner reach temperatures higher than the melting point of these metals. Therefore, most soft materials like lead are not suitable because they would simply melt away and would provide a health hazard.

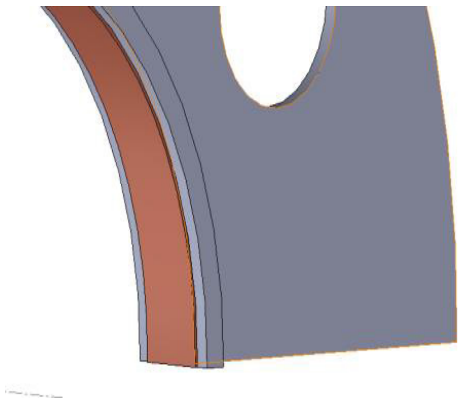


Figure 2-11: Soft element (e.g. lead)

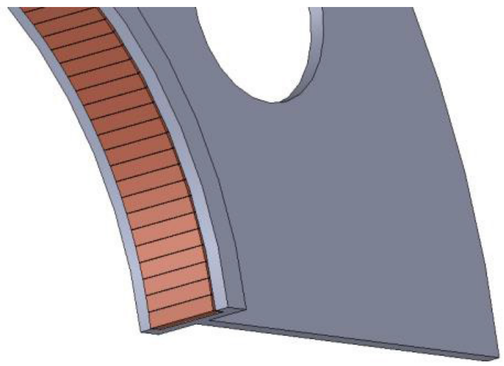


Figure 2-10: Series of contact elements

2.3. Conceptual phase

The following chapter shows the design process for the improved efficiency concepts. For an honest comparison between the concepts and the original design, the overall dimensions, barrel diameter and burner dimensions were kept as much identical as possible throughout the concepts.

2.3.1. Concept development

Using the findings in the previous paragraph four concepts were developed. For convenience, the concepts were labelled based on their working principle: “Labyrinth” (concept 1), “Full Discs” (concept 2), “Twist” (concept 3) and Spiral” (concept 4).

2.3.2. Concept 1: Labyrinth

The “Labyrinth Concept” (Figure 2-12) was created using the principle of increased contact area. The path of the flue gas is enlarged by a labyrinth.

In this concept, fuel enters the burner in the same way as in the original design. The fuel is ignited and the flue gas travels along the labyrinth to reach the exhaust.

The advantages of this concept are:

+ Flue gas stays in the burner for a longer time so more energy can be absorbed
+ The surface area in contact with the flue gas and barrel is larger
+ The speed, thus the turbulence is maintained throughout the path of flue gas because of a decreasing flow area

The disadvantages of this concept are:

- A method of heat transfer between the labyrinth ‘sleeve’ and the barrel needs to be developed
- Hot spots with thermally induced mechanical stress will occur due to a temperature range (flue gas cools while reaching the exhaust)
- Construction issues

The advantages and disadvantages will be addressed in the second paragraph on ‘Concept selection’.

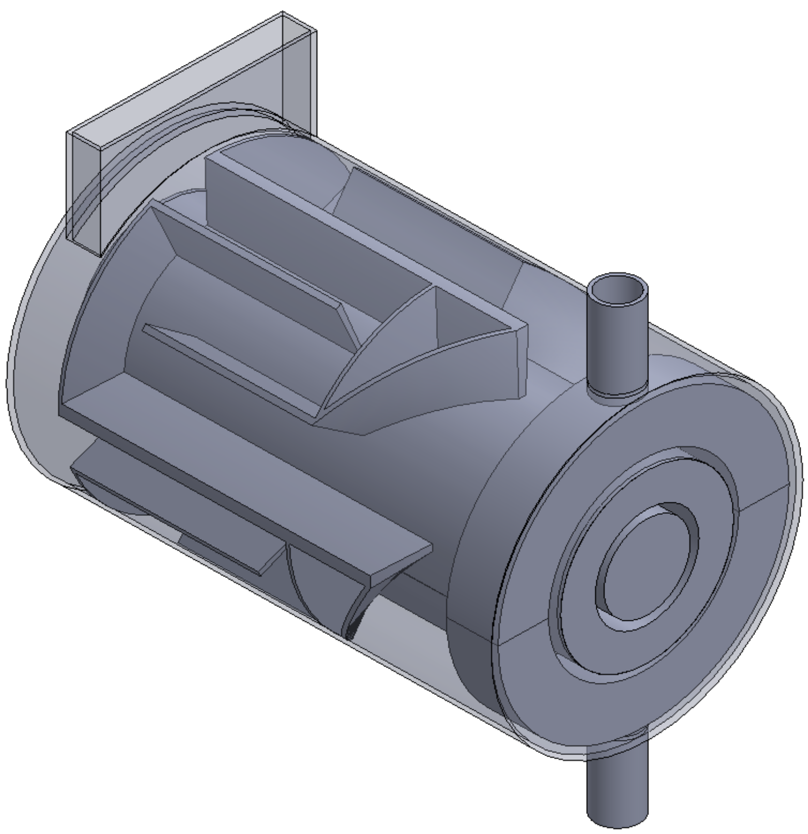


Figure 2-12: Concept 1: Labyrinth

2.3.3. Concept 2: Full Discs

The “Full Disc Concept” (Figure 2-13) was generated using a combination of the principles “increased contact area” and “turbulence”. Discs are placed in the gas flow, with holes to direct the flow of flue gas.

In this concept fuel enters in the same way as in the previous concept. The flue gasses will reach the first disc where their path is obstructed and flow will be diverted to the nearest hole. While passing the disc, heat is transferred. After passing the first disc it reaches the second disc etc.

The advantages of this concept are:

+ Flue gas stays in the burner for a longer time due to the constant diversion of flow
+ The surface area in contact with the barrel is bigger
+ Turbulence is maintained due to constant diversion of flow
+ The discs can be individually mounted on the barrel to aid construction simplicity

The disadvantages of this concept are:

– Multiple discs have to be added to the construction, they cannot be attached as one single unit
– It is complicated to mount the discs on the barrel
– Expansion of the discs due to heating needs to be kept in mind during mounting as it is important to ensure constant contact between the discs and the barrel.

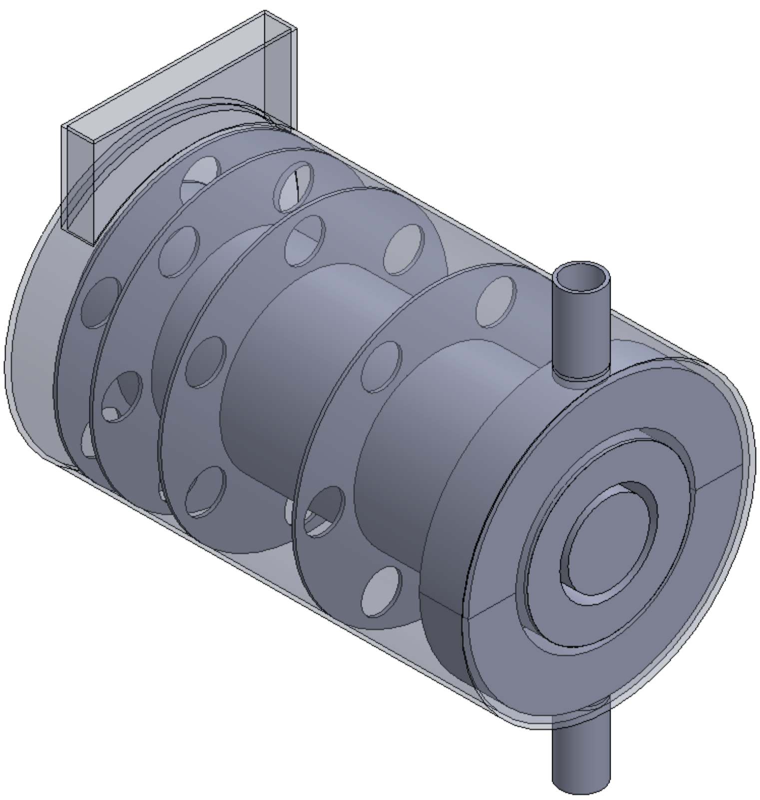


Figure 2-13: Concept 2: Full Discs.

2.3.4. Concept 3: Twist

In the "Twist concept" (see Figure 2-14) the flue gas is led through a series of fins which are twisted around the barrel. The fins are mounted on some sort of 'sleeve' around the barrel.

The surface area of the flow is also reduced because the pitch of the spiral is decreasing towards the exhaust. This is done to maintain turbulence throughout the flow. Surface area is also improved because of the great number of fins.

The advantages of this concept are:

+ Flue gas stays in the burner for a longer time so more energy can be absorbed
+ The surface area in contact with the flue gas and barrel is bigger
+ Speed, thus the turbulence is maintained throughout the path of flue gas because of the decreasing flow diameter
+ Temperature decrease is constant to reduce thermally induced mechanical stress

The disadvantages of this concept are:

- A method of heat transfer between the twisted 'sleeve' and the barrel has to be developed
- Difficulties in construction due to the complex twisted shape

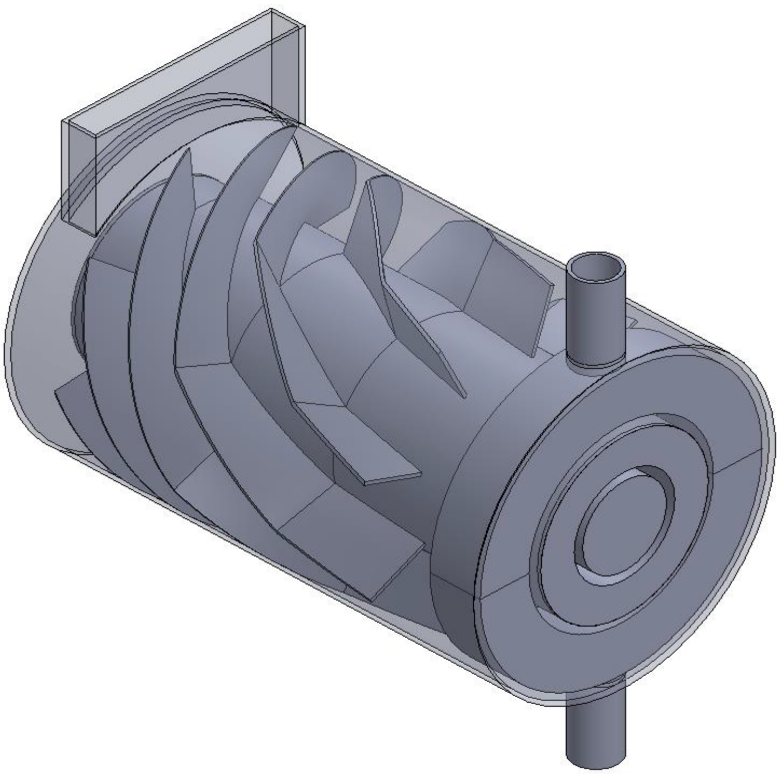


Figure 2-14: Concept 3: Twist.

2.3.5. Concept 4: Spiral

In the "Spiral Concept" (see Figure 2-15) the flue gas is led around the barrel using spiral fins mounted on a sleeve.

The surface area of the flow is reduces towards the end of the heater because the pitch of the spiral decreases towards the exhaust. This is done to maintain turbulence throughout the flow. Because of the spiral the surface area is a lot bigger than in the original design.

The advantages of this concept are:

+ Flue gas stays in the burner for a longer period of time, so more energy can be absorbed
+ The surface area in contact with the flue gas and barrel is bigger
+ The speed, thus the turbulence is maintained throughout the path of flue gas because of the decreasing flow diameter
+ The temperature decrease is gradual to reduce thermally induced mechanical stress

The disadvantages of this concept are:

– A method of heat transfer between the 'sleeve' and the barrel has to be developed
– Difficulties in construction due to the complex spiral shape

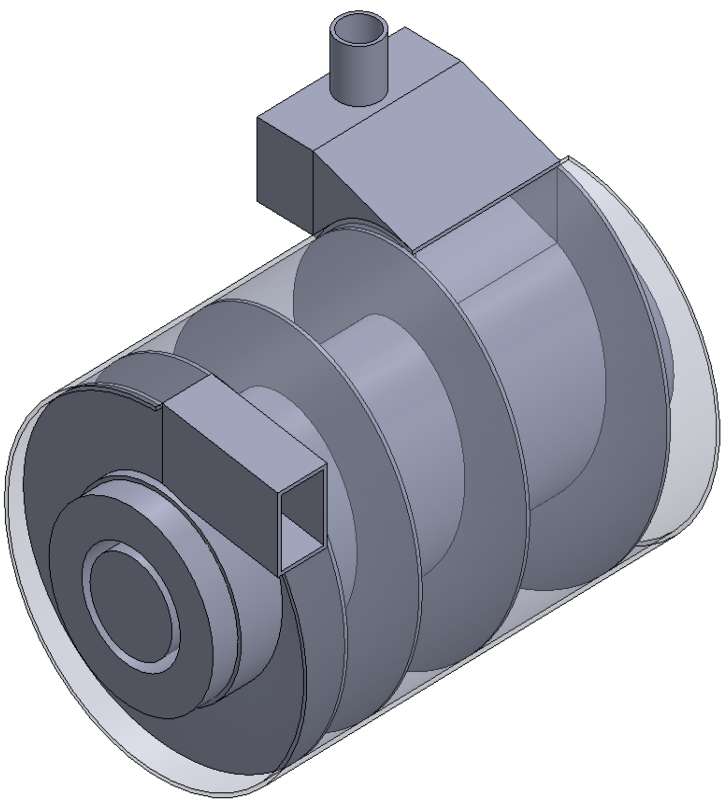


Figure 2-15: Concept 4: spiral.

2.4. Preliminary Concept Selection

Because simulation of all concepts is expensive and time consuming, a preliminary choice was made to speed up the process. All concepts feature an increase in surface area to improve heat transfer and all the concepts feature means to increase and maintain turbulence in the gas flow. None of the concepts feature a radiation plate because the barrel is a very thick object and it will not be subjected to thermal stresses because heat is quickly dissipated throughout the material due to high thermal conductivity. A radiation plate would only cause loss of heat transfer.

Two main criteria for the selection of the concept are costs and producibility. This means that it must be possible to economically construct the concept. All concepts but the second feature some kind of complicated 'sleeve' which must be constructed to incredibly tight tolerances and must be split in half to allow mounting. Furthermore, the heat must be transferred from the sleeve to the barrel which adds another material to the equation.

The second concept features individual discs which can be easily split in half to aid construction. Additionally, the surface area can easily be tuned by adjusting the number of discs to a barrel. The diameter of the holes can be adjusted to increase and decrease turbulence. Concluding, the second 'Full Disc' concept is the most flexible and the most viable option.

2.4.1. Temperature distribution and efficiency

To validate the assumption that this concept is an improvement over the Protype II, a simulation in Ansys CFX was performed. The results are presented in Figure 2-16.

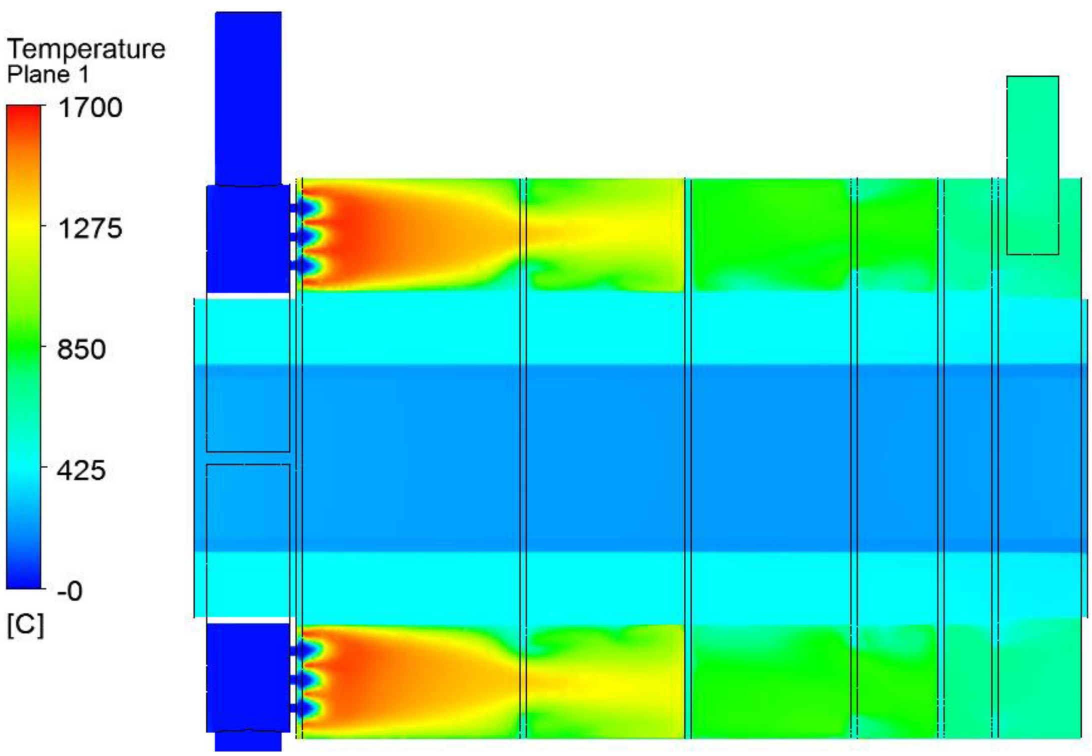


Figure 2-16: Improved design disc concept: temperatures.

For comparison purposes the boundary conditions of the burner were kept the same as for Prototype II. It can clearly be seen that the temperature of the flue gas decreases towards the exhaust after passing each disc. The exhaust temperature of this concept was calculated to come to 663 °C compared to 782 °C in Prototype II concept. This means that more heat is extracted from the flue gas and added to the polymer flow. The efficiency of this optimally constructed concept was calculated at 65.0 %. The maximum polymer temperature was calculated to increase from 228 to 240 °C.

2.4.2. Disc / barrel contact

The efficiency was calculated to increase with approximately 21%, i.e. 11 % points, assuming perfect contact between the discs and the barrel. The simulation featured a solid/solid connection between the disc and the barrel as if it was welded on (see Figure 2-17). The temperature profile as a consequence of the extra heat transferred from the disc is also visible.

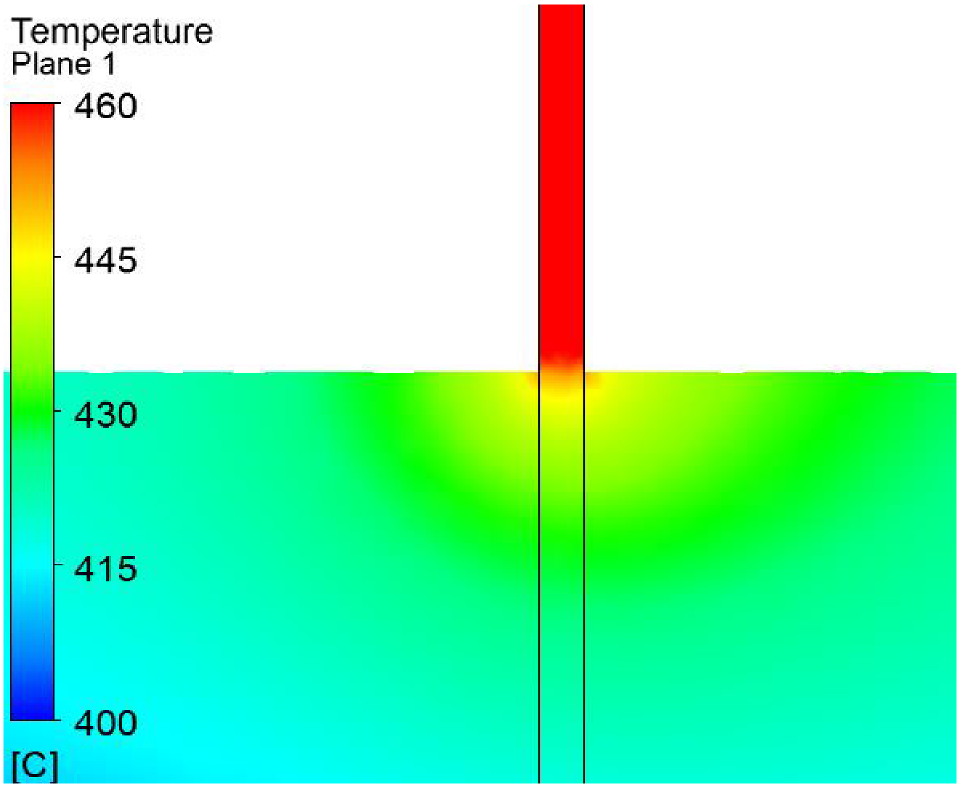


Figure 2-17: Discs in the improved design heater: temperature profile at disc foot.

2.4.3. Gas stream lines

Figure 2-18 shows a simulation of the flow of the gas ("stream lines"), showing the turbulence caused by the presence of the holes in the discs.

In this image the diversion of the flue gas due to the holes and the increased turbulence is visible. The lines
indicate the path travelled by the flue gas in order to reach the exhaust. They have to navigate a great number of disturbances in order to proceed so the mechanism of maintaining turbulence works.

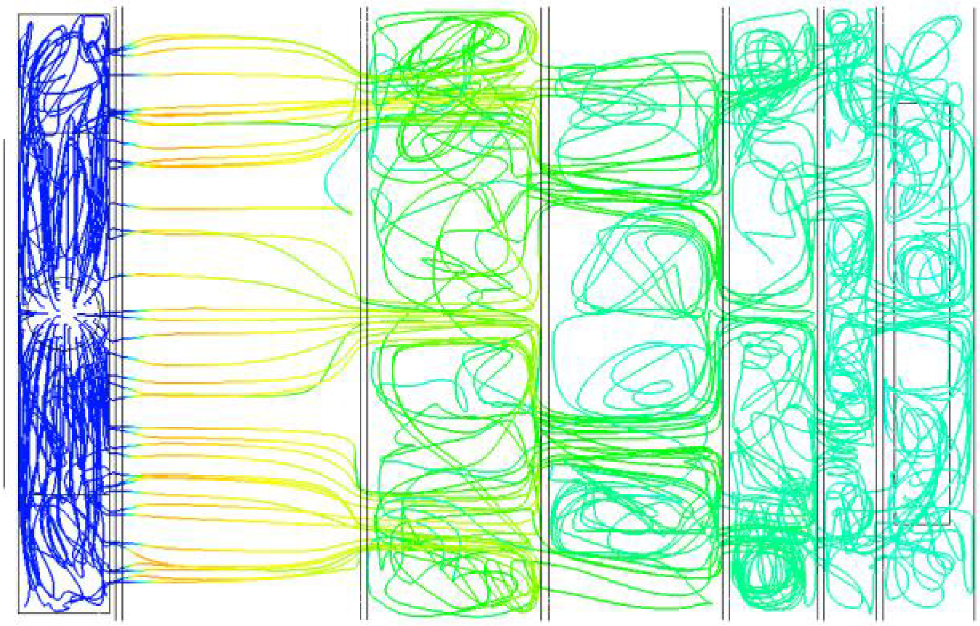


Figure 2-18: Improved design discs: gas flow.

2.4.4. Pressure drop

Figure 2-19 shows the calculated total pressure drop in the burner. For this concept the pressure drop was calculated at 80 Pa. This is acceptable for a burner, since, as discussed before, the acceptable maximum pressure drop may be as high as 300 Pa.

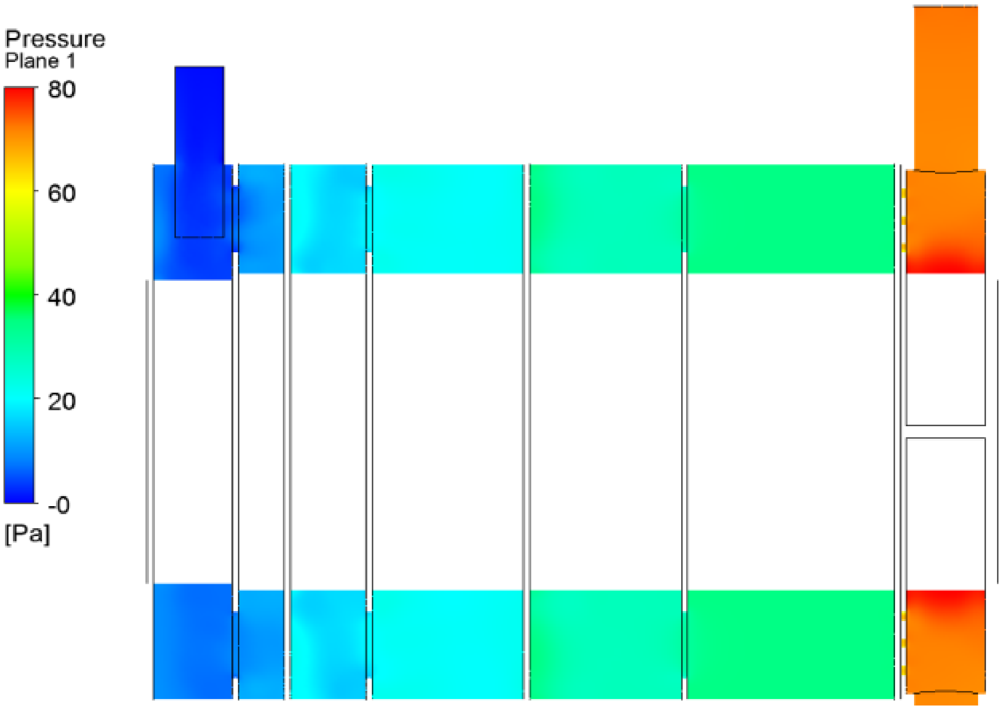


Figure 2-19: Improved design discs: pressure drop.

2.5. Final concept design details

In order to turn the disc concept into an industry acceptable solution, a number of things had to be addressed. To summarize:

- The disc design had to be optimized so they can be fastened onto the barrel
- Contact between the disc and the barrel needed to be ensured
- The pressure drop had to be acceptable

To address these points, the disc were re-designed to consist of a number of smaller ‘elements’ which could be clamped onto the barrel. The design of the elements is featured in Figure 2-21. A ring is constructed from 12 of these segments (see Figure 2-22) to achieve the ‘disc’ shape featured in the previous concept.

Figure 2-20: Disc element clamp.

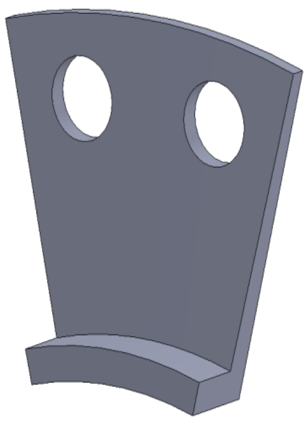


Figure 2-21: Single disc element.

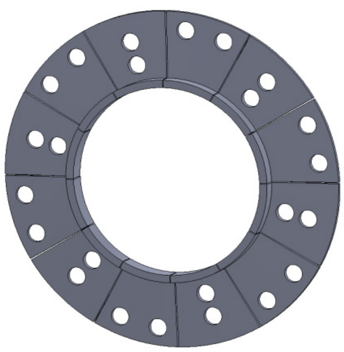


Figure 2-22: Disc of elements.

To increase turbulence the holes in the elements were decreased in diameter but increased in number, while the total surface area of the holes was kept the same as in the concept to maintain a low pressure drop.

The preferred material of the segments was identified as copper, because of its high heat transfer rate.

A disadvantage of copper is the high thermal expansion coefficient, which causes the segments to expand a little bit more than the barrel that the full disc is clamped onto (by a specifically designed clamp which closely resembles an ordinary hose clamp (see Figure 2-20). To compensate for this, the clamp has be fixed to the barrel with a certain amount of pre-tension, to ensure sufficient contact force when the heater will be operated.

These adaptations needed of course more simulations using Ansys CFX to compare it to the original design.

2.6. Final concept validation

Based on the finding in the previous paragraph, a final concept (see Figure 2-23) was developed for further validation using Ansys CFX.

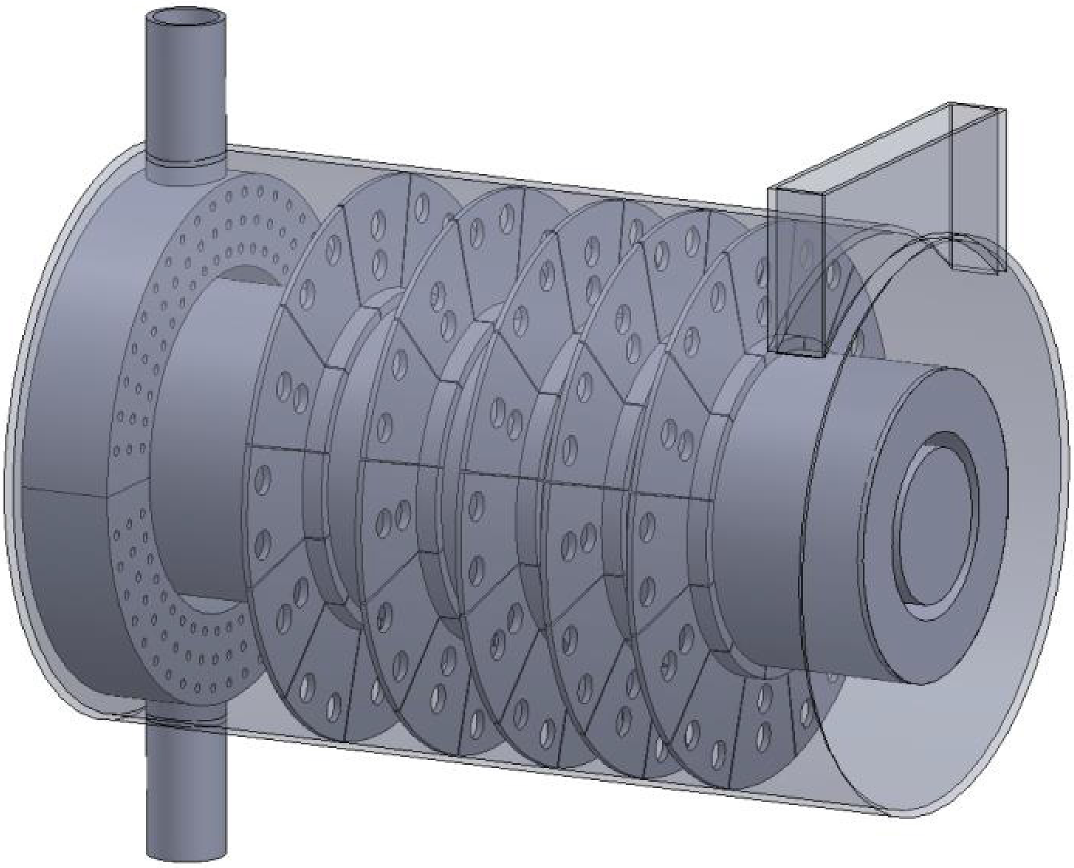


Figure 2-23: Improved design: final concept.

2.6.1. Temperature distribution and efficiency

The boundary conditions for this final concept were kept the same to the original design to ensure a valid comparison. The temperature diagram resulting the Ansys CFX simulation is given in Figure 2-24.

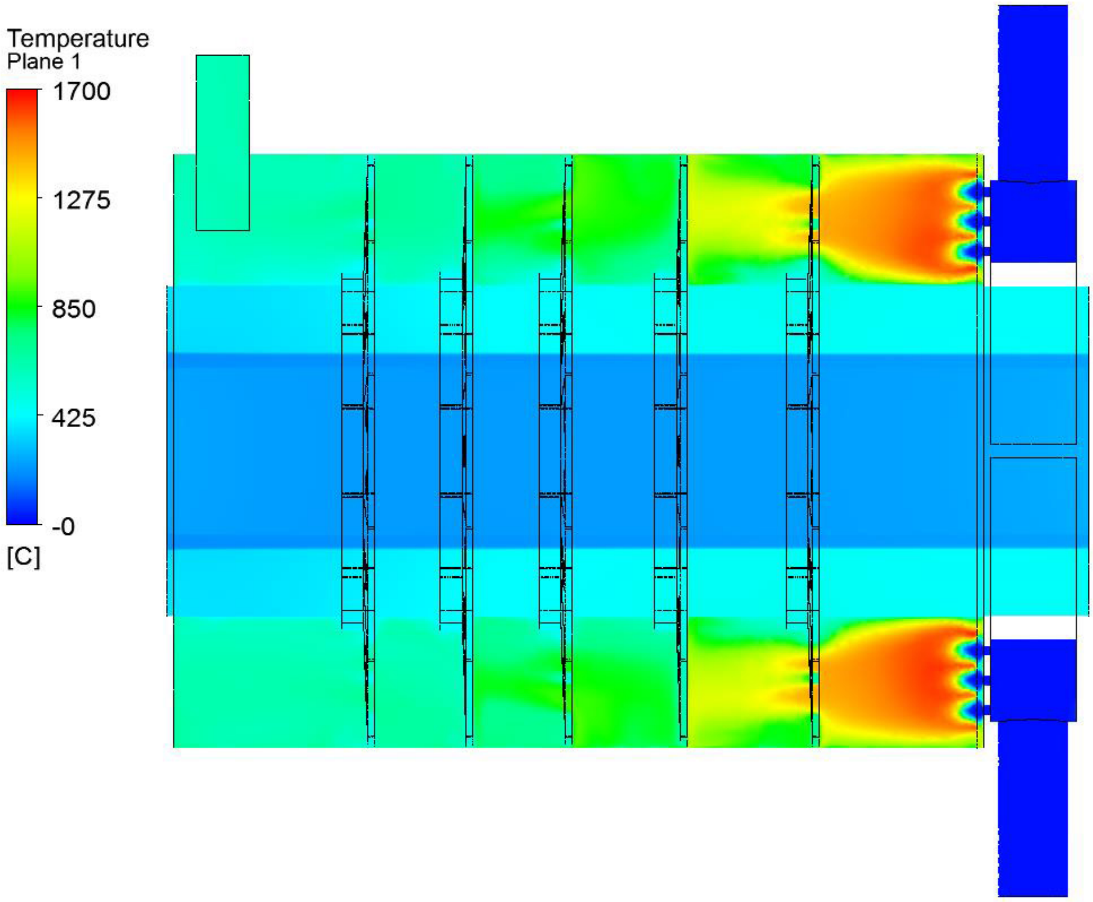


Figure 2-24: Segmented Disc concept: temperature distribution.

Similar to the ‘Full Disc’ concept, in the “segmented Disc” concept the temperature gradually decreases every time the gas passes through a disc. The polymer flow at the exit was calculated to come to 241 °C , which is an increase of 8 °C in comparison to the original design. The efficiency was calculated at 66.6 %, an increase of approximately 24 % (13 % points) in comparison to the original design.

2.6.2. Pressure drop

The pressure drop across this burner (see Figure 2-25) was calculated to be around 74 Pascal. This is lower than the 'idealized' concept meaning there is the opportunity to place more discs on the barrel without negatively affecting the pressure drop (because of the high margin up to 300 Pascal). The pressure drop per disc is about 7 Pascal.

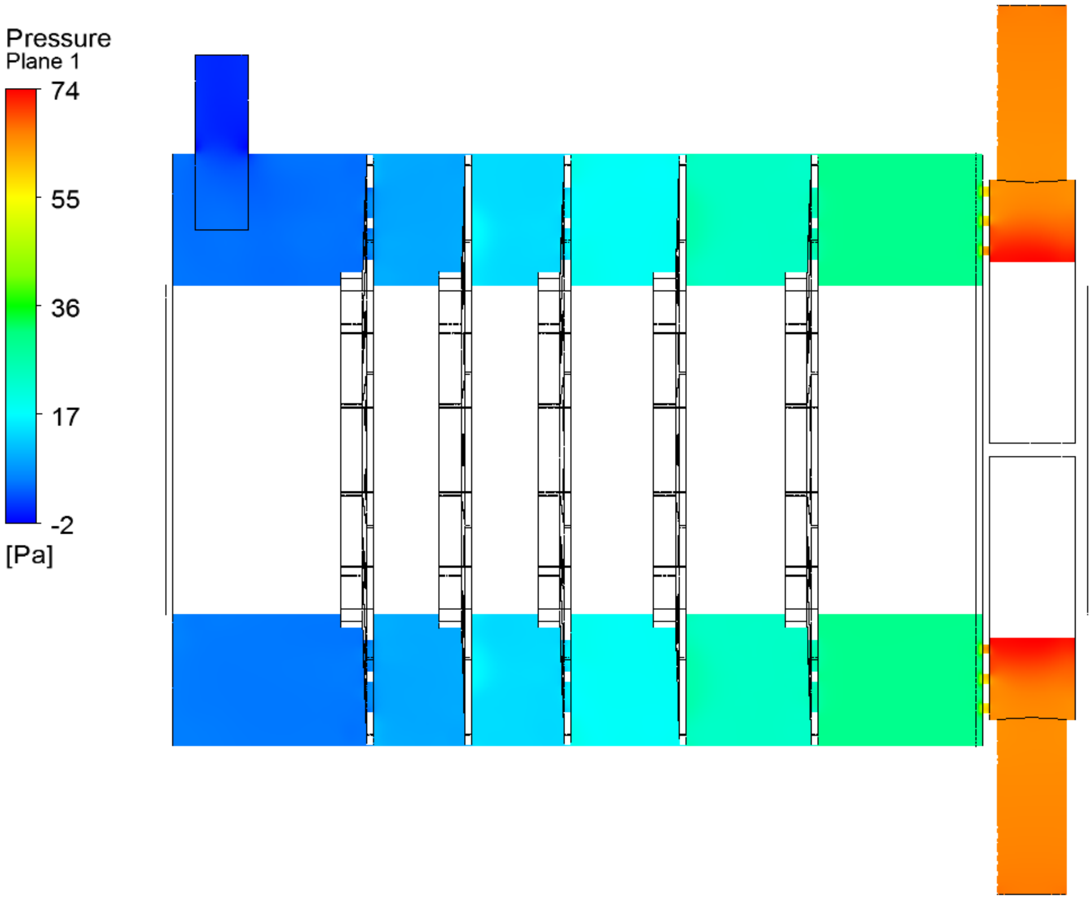


Figure 2-25: improved design: pressure drop.

2.6.3. Gas stream lines

Figure 2-26 gives a simulation of the flow of the gas, showing the effect of the segments containing the holes.

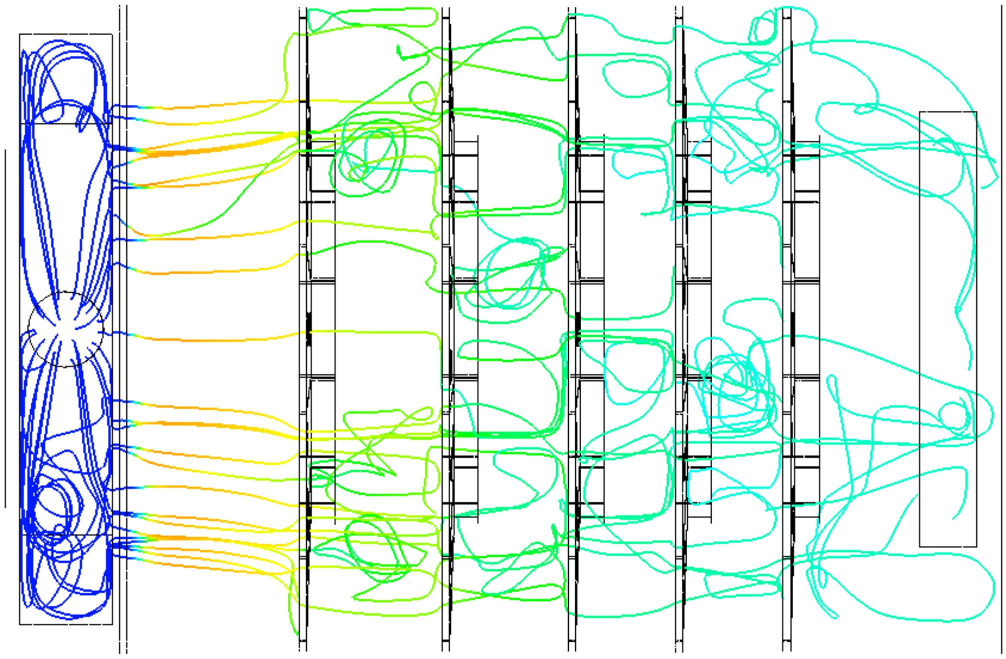


Figure 2-26: Improved design: gas flow.

Again it is visible that in the simulation the flow is disturbed by the holes and elements, so the temperature of the flue gas is evenly distributed. This will contribute to a better heat transfer.

2.7. Conclusions

In order to come up with an improved thermal design for a gas fuelled heater, three types of heaters were evaluated by means of thermal simulations using Ansys CFX. Table 2-1 provides an overview of the resulting data.

		Source of data	Prototype II	Full disc (concept)	Segmented disc (final concept)	Unit
Design data	Overall diameter	Design	180	180	180	[mm]
	Overall length	Design	280	280	280	[mm]
	Barrel diameter	Design	100	100	100	[mm]
	Barrel length	Design	280	280	280	[mm]
	Barrel oil flow area	Design	0,00271	0,00271	0,00271	[m^2]
	Number of discs	Design	n.a.	5	5	[-]
	Outer diameter of disc	Design	n.a.	176	178	[mm]
	Inner diameter of disc	Design	n.a.	104	104	[mm]
	Holes per disc	Design	n.a.	6	24	[mm]
	Diameter holes	Design	n.a.	22	9.5	[mm]
	Number of segments	Design	n.a.	1	12	[-]
Gas	CH4	Simulation input	0,0422	0,0422	0,0422	[kg/kg]
	O2	Simulation input	0,2110	0,2110	0,2110	[kg/kg]
	N2	Simulation input	0,7468	0,7468	0,7468	[kg/kg]
	CO2	Simulation input	-	-	-	[kg/kg]
	H2O	Simulation input	-	-	-	[kg/kg]
	NO	Simulation input	-	-	-	[kg/kg]
	Total	Simulation input	1,0000	1,0000	1,0000	[kg/kg]
	simulation type	Simulation input	radiation incl.	radiation incl.	radiation incl.	[-]
	Mass flow per inlet	Simulation input	0,001365	0,001365	0,001365	[kg/s]
	Total mass flow (2 inlets)	Calculated	0,00273	0,00273	0,00273	[kg/s]
	Temperature in	Simulation input	20	20	20	[°C]
	Temperature out	Simulation output	782	663	627	[°C]
	Lower heating value CH4	-	50	50	50	[MJ/kg
	Thermal input	Calculated	5,7603	5,7603	5,7603	[kW]
" Polymer " (Thermal oil)	Flow (velocity)	Simulation input	0,0508	0,0508	0,0508	[m/s]
	Density	Calculated	282,8	282,8	282,8	[kg/m^3]
	Flow (mass)	Calculated	0,039	0,039	0,039	[kg/s]
	Temperature in	Simulation input	200	200	200	[°C]
	Temperature out	Simulation output	233	240	241	[°C]
	Specific heat	-	2400	2400	2400	[J/kgK]
	Heat absorbed	Calculated	3,0888	3,744	3,8376	[kW]
Key results	Thermal efficiency	Calculated	**53,6%**	**65,0%**	**66,6%**	%
	Pressure drop	Simulation output	**79**	**80**	**74**	[Pa]

Table 2-1: Resulting data from three simulations.

From the results of the simulations it can be concluded that the thermal re-design of the heater, applying a series of disks with holes (using the operation principles of fins, a labyrinth and turbulence) was proven to be successful. The overall energy efficiency of the heater was raised from 53.6% (preliminary design) tot 66.6% (final concept), meeting the pre-set (albeit arbitrary) design goal of a thermal efficiency increase of 20% (10% points). The validated concept shows a solid basis for further constructional development and re-design.

2.8. Recommendations

The following conclusions are formulated to aid the next step in the design process: to build the prototype for real life testing.

2.8.1. Alternative geometries

Because the pressure drop was found to be quite low, it is an option to place more 'discs' on the barrel to enlarge the heat transfer and thus the efficiency. The only limitation in the number of discs will be the available space. The pressure drop is about 7 Pascal per disc so a large number of discs can be added to reach a total pressure drop of 300 Pascal.

2.8.2. Clamping device

The clamping device featured in chapter 4 is very basic in its design. Although mounting the elements on the barrel with a pre-tensioned clamp can be an acceptable working principle, it is highly recommended to verify this working principle in practice.

2.8.3. Burner

The burner featured in the simulations was near identical to the one used in the original design. The scope of this report was to develop a better way to transfer heat from flue gas to an injection moulding barrel. Placing the burner differently, e.g. radially vs. the prototype axial burner, could be a way to further optimise the system.

2.8.4. Exhaust

The prototype exhaust was constructed using a rectangular channel, just as in prototype II, to allow for comparison. Because the discs in the new concept can be placed very closely together, the burner can be constructed shorter than before, which allows for all kinds of exhaust shapes, and therefore room for improvement.

2.8.5. Seals

The prototype was designed with a very complicated sealing method. This is not viable for a commercial product so it needs to be simplified. One way to achieve this is the seal featured in Figure 2-27.

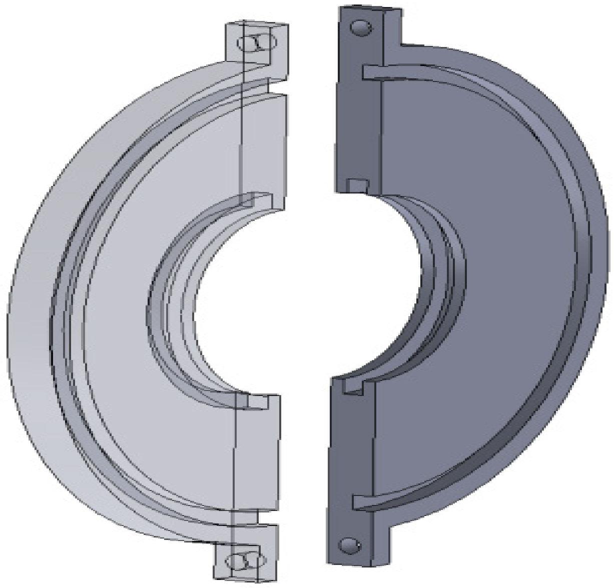


Figure 2-27: Suggestion for improved end seal.

This seal consists of two plates with recessed channels that the gasket can be placed into. Once joined together, the combined plates will cover the ends of the burner and can be clamped onto the insulated shell and hold it in its place. An impression of the finished burner is featured in Figure 2-28 .

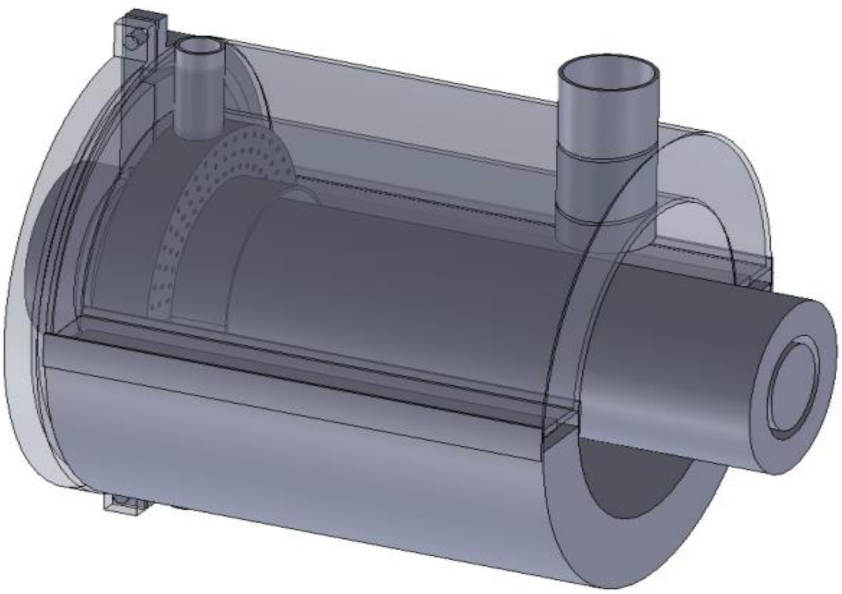


Figure 2-28: Suggestion for improved shell sealing

3. Constructional Re-design

3.1. Introduction

In the previous chapter a thermal re-design of a gas fuelled heater was presented aimed at improved thermal efficiency. It was found that the thermal efficiency can be drastically improved by applying a variety of operating principles like fins or a labyrinth. The overall energy efficiency of the heater was raised from 53.6% (preliminary design) to 66.6% (final concept). The final concept, validated by Ansys-CFX simulations, is a solid basis for further constructional development and re-design.

This chapter summarises the main findings of the second part of the study: a constructional re-design. Additionally, this part of the study addresses some of the constructional and assembly flaws found in earlier prototypes.

3.2. Evaluation of existing types

This chapter provides a short survey of earlier developed models and concepts, including an overview of their observed strengths and weaknesses. The results will be used as the starting point for the constructional re-design.

3.2.1. Prototyype I

Prototye I (see Figure 3-1) features two steel shells fixed with nuts and bolts. The working principle is based on a so called radiation plate.

The identified strengths and weaknesses are:

+ Robust design

– Costly, complicated design
– Complicated assembly
– Prone to thermal stress (cracks detected)

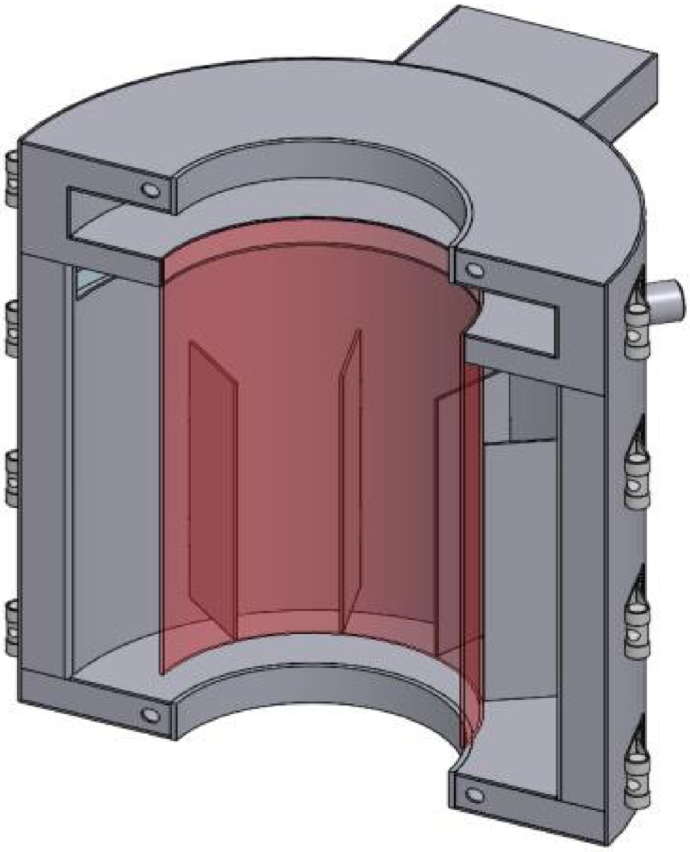
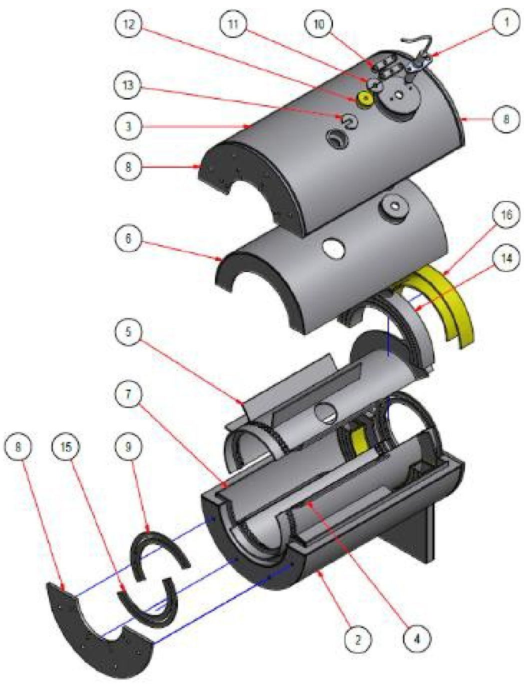


Figure 3-1: Prototype I.

3.2.2. Prototype II

As Prototype I proved to be mechanically unstable, a new design, prototype II (see Figure 3-2) was developed based on the same operational principle of a radiation plate, but solving the problems of thermal cracking.



Pos.	Qty.	Description	Part nr.	Material
1	1	Ontsteker	4-6-3	Generic
2	1	Buitenmantel onder	KB2013-A01	Stainless Steel
3	1	Buitenmantel boven	KB2013-A02	Stainless Steel
4	1	Binnenmantel onder	KB2013-A03	Stainless Steel
5	1	Binnenmantel boven	KB2013-A04	Stainless Steel
6	1	Tussenmantel boven	KB2013-A11	Stainless Steel
7	1	Tussenmantel onder	KB2013-A12	Stainless Steel
8	4	Sluitplaat	KB2013-P13	RVS 304
9	4	Sluitring groot	KB2013-P22	RVS 304
10	2	Klemstrip sensor	KB2013-P24	Generic
11	2	Sensorring boven	KB2013-P25	RVS 304
12	1	Afdichting sensor	KB2013-P26	Generic
13	1	Sensorring onder	KB2013-P27	253 MA
14	2	Branderbuis	KB2013-P29	253 MA
15	4	Sluitring klein	KB2013-P31	RVS 304
16	2	Branderpakking	KB2013-P32	Default

Figure 3-2: Prototype II Exploded view.

This heater model was built and tested, during which the following strengths and weaknesses were identified:

+ No thermal cracking due to separated inner and outer covers or shells
+ Allowance for thermal expansion in all parts
+ Easy assembly of outer covers or shells
+ Easy assembly of the ignition mechanism
+ Heat resistant MA253 material, limited corrosion

– Complicated sealing system due to the two separate shells, inconvenient assembly, which does not allow these heaters to be installed in series (“head-tail”)
– Awkward assembly of radiation plate
– Moderate thermal efficiency of 41% (actual test result), due to high temperature of exhaust gasses

3.2.3. Final concept of thermal re-design

The development and validation of this model (Figure 3-3) was described in chapter 2. It was concluded from simulations that the thermal efficiency came to 66.6%.

Since the design was aimed at increased efficiency, some constructional issues still needed to be solved:

- Sealing system
- Design of the disc elements
- Assembly of the disc elements into one complete disc
- Disc to barrel mounting
- Thermal stress prevention

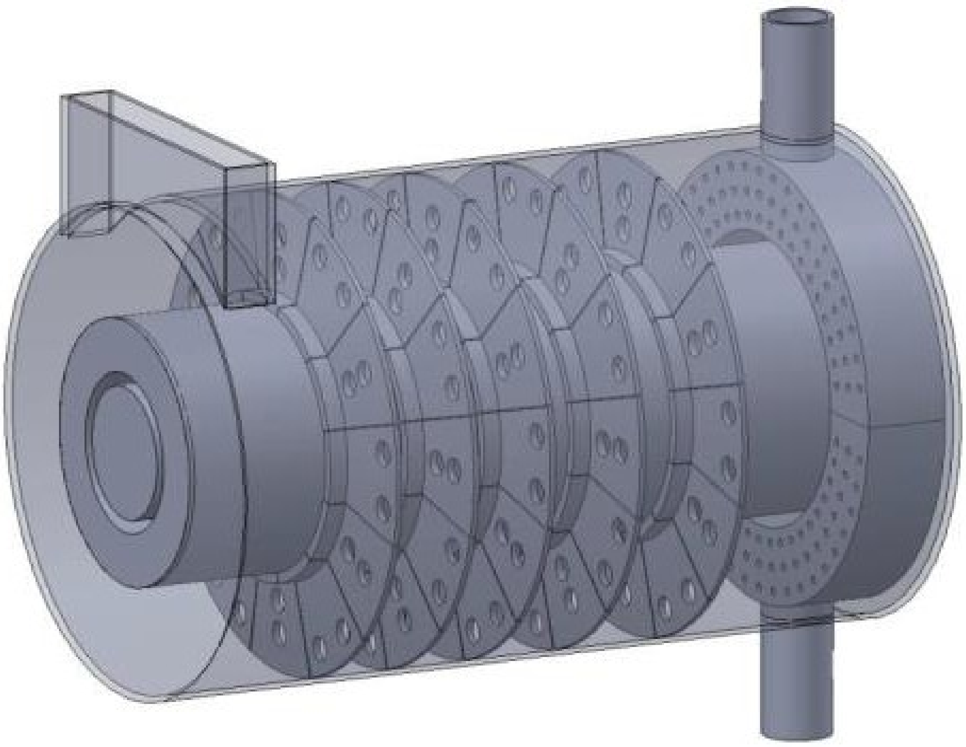


Figure 3-3: Final concept of thermal re-design

3.3. Re-design

Based on the Re-design final concept, a detailed design and prototype needed to be developed. First the requirements were identified, in the next step the conceptual design was developed followed by a detailed design aimed at production.

This section of the report provides a short insight into the process of re-design.

3.3.1. Requirements

Based on stakeholders discussions, the following list of requirements was produced:

Easy assembly	To facilitate easy assembly, reduce the number of parts and components
Easy production	All parts and components must be easy to produce
Assembly in series	“Head-to-tail” assembly of the heaters must be possible (mounted in series)
Discs	The operational principle of discs to achieve ao turbulent flow, should be included
Gas tight chamber	The heater shall be completely gas-tight, no leakage of gas is permitted
Easy servicing	Parts that need replacing should be easy to access and assemble
Limited pressure drop	The pressure drop should not exceed 300 Pa

3.3.2. Concept details: Discs

The discs incorporate the functions of heat extraction (from the gas) and heat transfer (to the barrel), a process that is optimised by the turbulent flow these discs create.

During the design process, the disc concept evolved to a series of 12 elements, mounted on the barrel using a standard hose clamp (see Figure 3-4). The main reason to choose 12 separate elements was to compensate for the thermal expansion of the disc. Using this design, the discs elements can expand freely, while contact between the foot of the element and the barrel remains intact.

Fastening the hose clamp was done with pre-tension to compensate for loss of contact force between foot and barrel due to thermal expansion of the clamp ring.

The final shape of the disc elements (dimensions, edges, location of holes) is the sum of recommendations made by manufacturing specialists and is aimed at a reduction of production costs and time. Material selection led to AISI 310, a heat resistant stainless steel with good machining properties.

Figure 3-4: Development of disc, elements and clamp (impression).

3.3.3. Concept details: hull, inner and outer shells

The hull incorporates all elements of the heater. It provides a gas-tight and thermally insulated chamber fixed around the barrel. Main design challenges came from sealing and thermal expansion.

Through a series of design steps focused on but not limited to structure and form variation (see Figure 3-5), a hull consisting of an inner and outer shell was developed.

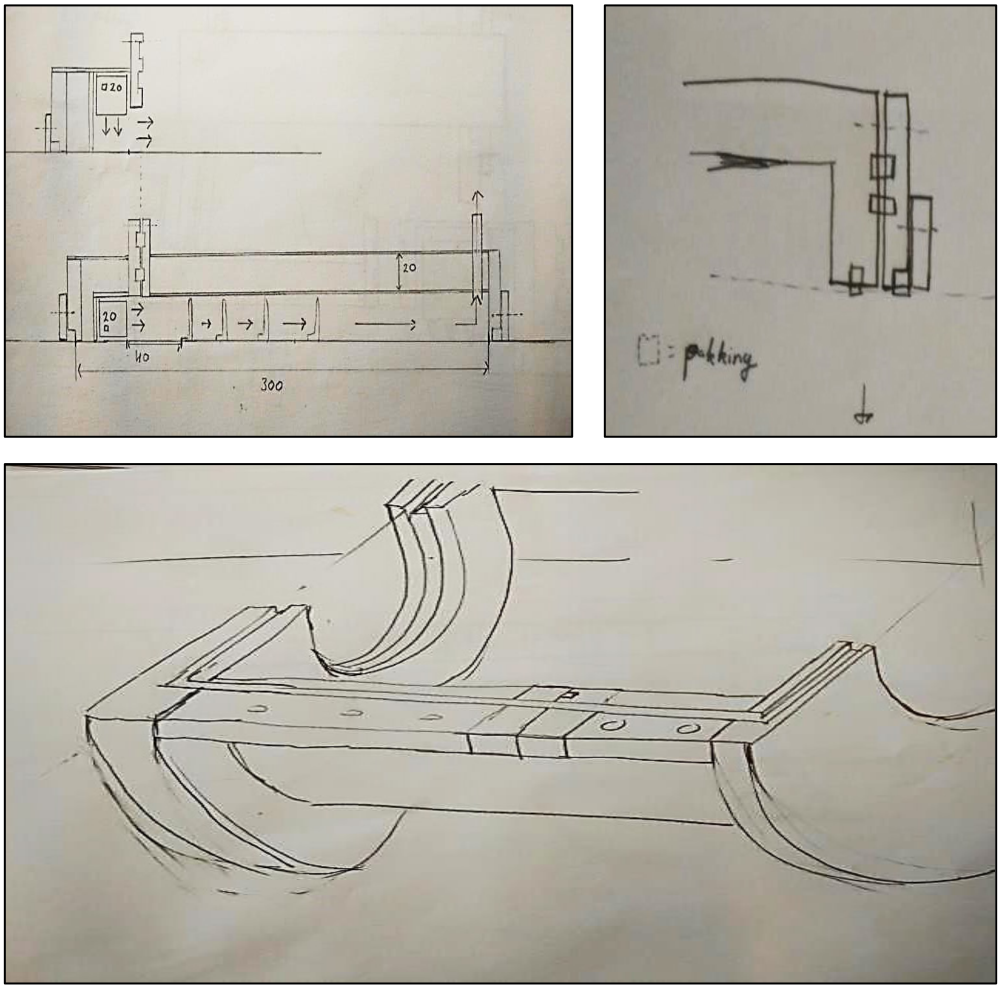


Figure 3-5: Design of shell and seal: structure and form variation (impression).

The inner shell consists of four parts: two shells and two burner units (see Figure 3-6The burner units are mounted on the inner shells using a heat resistant fibre reinforces graphite seal, to ensure a gas tight connection.

To allow for easy assembly, the inner shell needed to be composed of two parts. The contact area between the two shell parts was sealed applying the same heat resistant fibre reinforced graphite seal, which was placed in the seal groove, with a flat contact area towards the counter shell. The shell was made of AISI 310.

As the **outer shell** does not get exposed to excessive temperatures, it could be made of the lower cost AISI 304, which is still sufficiently heat resistant.

3.3.4. Other parts

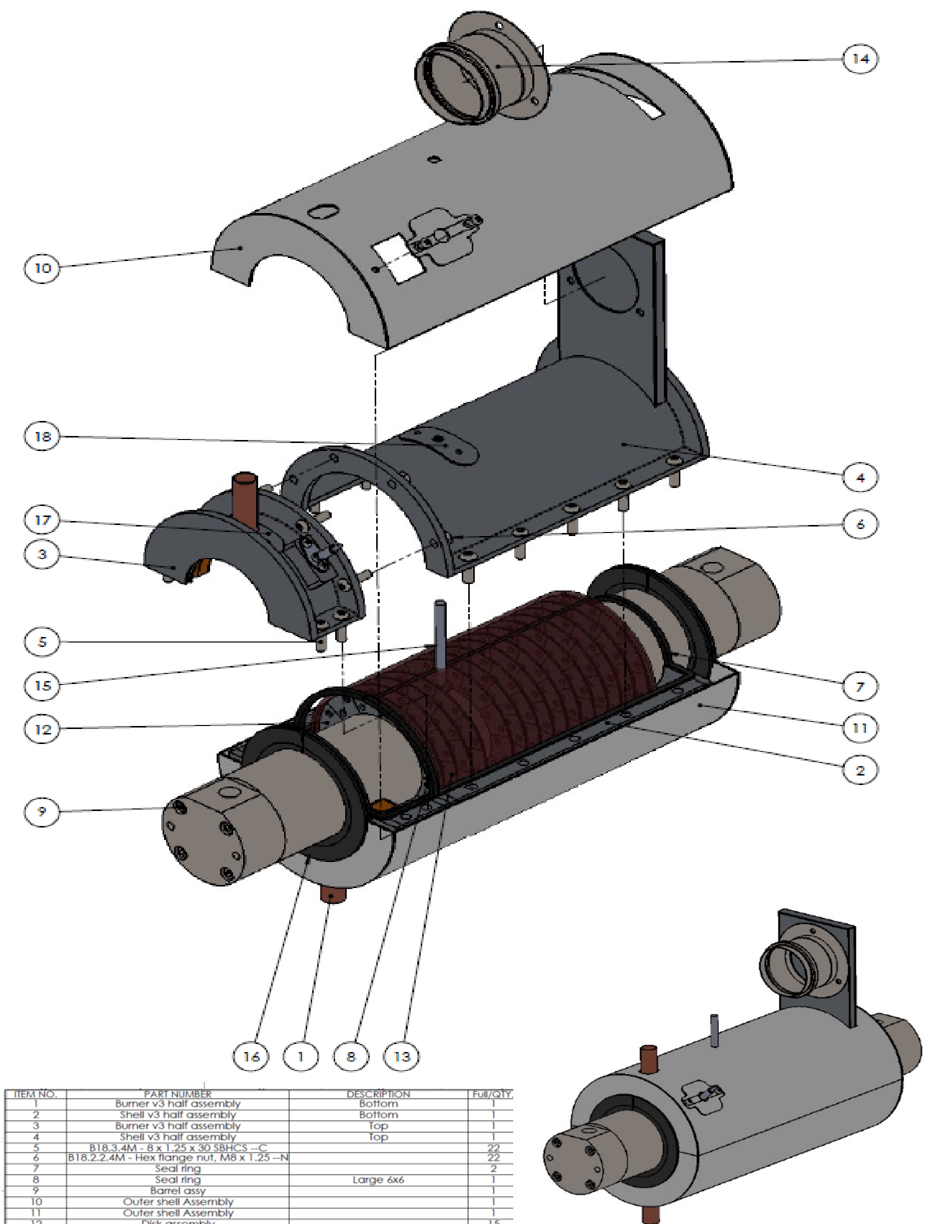
The ignition mechanism used in this assembly was an off-the-shelf solution. For the purpose of this prototype, the satisfactorily functioning burner head of the earlier prototype was used.

3.4. Final design

The result of the constructional re-design is documented in a full set of detailed drawings (see [2]). Here, the assemblies of the main components are briefly presented.

3.4.1. Total assembly

The exploded view assembly of the construction is presented in Figure 3-6. The main components are the burners (1, 3), the inner shells (2, 4), the outer shells (10, 11) and test barrel (9).

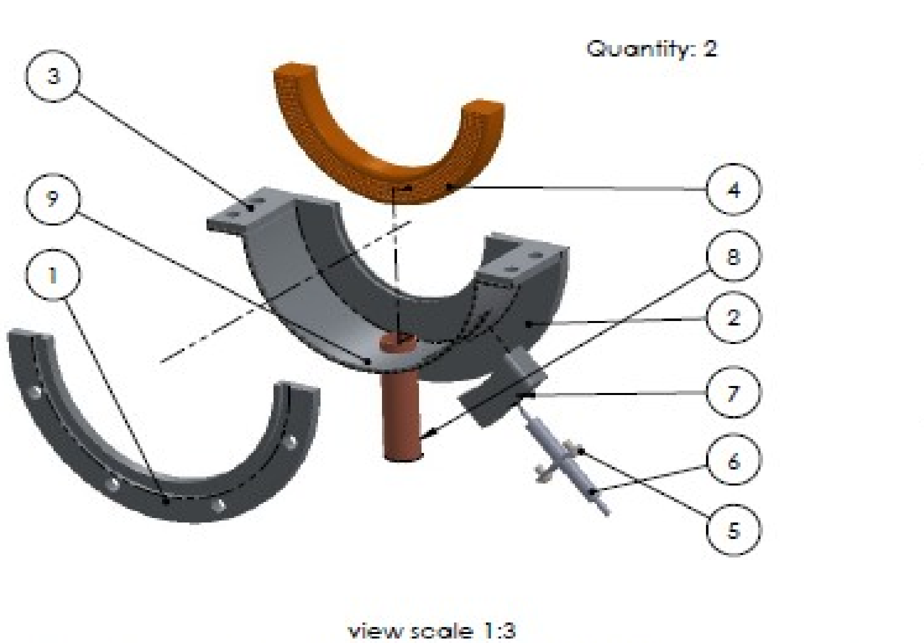


ITEM NO.	PART NUMBER	DESCRIPTION	Full/QTY.
1	Burner v3 half assembly	Bottom	1
2	Shell v3 half assembly	Bottom	1
3	Burner v3 half assembly	Top	1
4	Shell v3 half assembly	Top	1
5	B18.3.4M - 8 x 1.25 x 30 SBHCS --C		22
6	B18.2.2.4M - Hex flange nut, M8 x 1.25 --N		22
7	Seal ring		2
8	Seal ring	Large 6x6	1
9	Barrel assy		1
10	Outer shell Assembly		1
11	Outer shell Assembly		1
12	Disk assembly		15
13	Disk isolator		1
14	AANSLUITSTUK RVS316 80 L=75 VITON		1
15	Temperature probe assembly		1
16	Viton u-profile	Small 6x6	2
17	Seal plate gas supply		2
18	Seal plate probe		1

Figure 3-6: Final design of heater prototype

3.4.2. Burner assembly

Figure 3-7 shows the assembly of the burner, with the burner nozzle (4) and the ignition mechanism (6, 7) mounted on a welded construction (1, 2, 3) to be fitted on the inner shell.

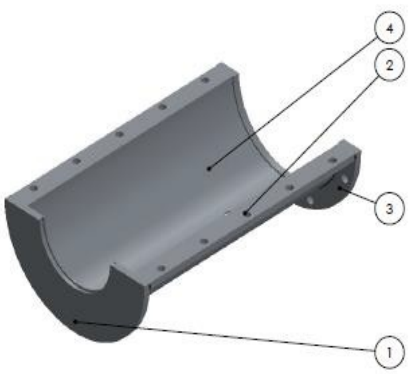


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Mid disk	Top with seal slot	1
2	End disk	Top	1
3	Side strip v3	Shorter, no seal slot	2
4	Burner nozzle axial		1
5	B18.3.4M - 5 x 0.8 x 8 SBHCS --N		2
6	Spark plug		1
7	Spark plug mount		1
8	Burner nozzle gas supply tube		1
9	Inner shell v2	Burner	1

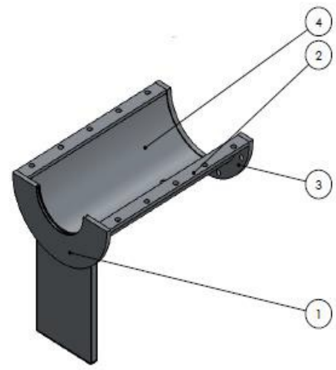
Figure 3-7: Burner assembly

3.4.3. Inner shells

Figure 3-8 shows the two inner shells of the final design. They come in two versions: one with flat sealing contact areas (left) and one with sealing grooves and gas outlet (right).



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	End disk	Pre milling	1
2	Side strip v3	Pre milling	2
3	Mid disk	Pre milling without seal slot	1
4	Inner shell v2	Shell Bottom	1

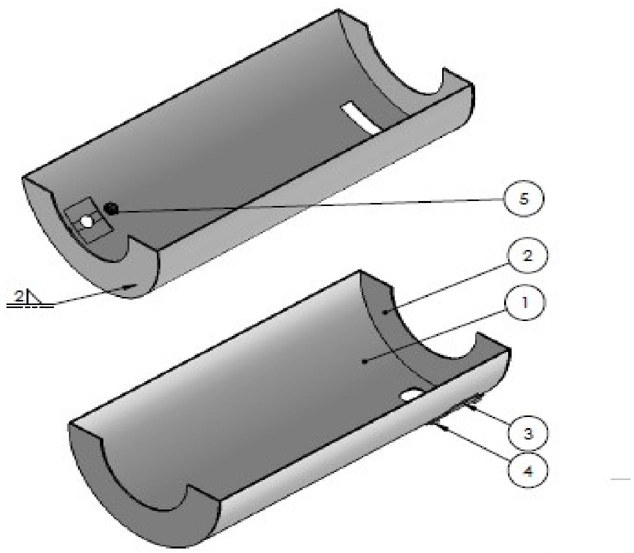


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	End disk	Top	1
2	Side strip v3	Without seal slot	2
3	Mid disk	Top without seal slot	1
4	Inner shell v2	Shell Top	1
5	Exhaust sheet 1		1
6	Exhaust sheet 2		1

Figure 3-8: Inner shells

3.4.4. Outer shells

The outer shells are presented in Figure 3-9. The space between inner and outer shells will be filled with an insulation material (glass wool).



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Outer shell		1
2	Shell end plate clip on		2
3	Outer shell lid		1
4	B18.3.4M - 6 x 1.0 x 10 SBHCS --N		2
5	B18.2.2.4M - Hex flange nut, M6 x 1 --N		2

Figure 3-9: Outer shell

3.5. Prototype III production

Detailed information on the production issues (work break down, detailed drawings, quotations) is given in [2]. Here, an outline of the production and assembly process is given.

3.5.1. Parties involved

Three parties were involved in the production of the prototype. Hoekman-Roestvaststaal in Nieuwleusen delivered the stainless steel plates and manufactured the shells. Hordal in Zwolle took care of the machining operations such as shell-grooves, disc elements and end plates. 3Force in Zuidbroek performed the precision welding.

3.5.2. Assembly

In [2] the details of the assembly can found including a manual. The assembly was executed by a researcher of the Professorship for Polymer Engineering at Windesheim.

3.6. Testing and evaluation

Full scale testing of Prototype III was not within the scope of this project, but a make shift test was carried out to get a feel for its performance.

3.6.1. Assembly

Easier assembly was one of the main objectives of the constructional re-design. Ease of assembly was tested using the 3D model and in real life. An assembly protocol in [2] provides further details.

In short, assembly proved to be much easier when compared to earlier models. Some attention is still needed for the laser cut parts, which should haven more play to allow for easier mounting. Additionally, the location of the valves needs be optimised. Apart from these details, ease of assembly was satisfactory.

3.6.2. Functionality

As a “quick and dirty” test, the heater was installed in a make-shift test unit consisting of the test barrel with mounted heater. A test medium (water, as a substitute for the polymer) flowed through the barrel. The temperature of the test medium was measured at the entrance and exit plus the flow rate. Additionally, the heater was visually checked on material integrity, especially with regards to thermal cracking.

Figure 3-10: Preliminary test set up of Prototype III.

3.6.3. Thermal efficiency

The heater was pre-tested under very basic conditions, with the objective to obtain an indication of the thermal efficiency of the new device (see Figure 3-10). Although the test conditions were not completely representative, the findings of this test are presented here.
During a 30 minutes test, the heater-barrel combination was brought in stationary state, with no fluctuation in temperature and flow. The temperature of the water input was 18 °C, whereas the water output temperature was 52 °C. The water flow rate was 0.022 kg/s. The power of the burner was estimated at 5.12 kW. Although the test set up was far from ideal, based on these figures a careful conclusion can be drawn that the efficiency of the heater was approximately 61.5%. Under similar conditions, Prototype II resulted in an efficiency of 41%.

Of course, testing with water at these kind of low temperatures and small ΔT cannot be compared to heating polymers at higher temperatures and larger ΔT. However, notwithstanding all the reservations regarding the test set up, the found efficiency is remarkably in line with the simulation results. Based on the combined results of simulations and testing it can however be concluded that the new design of the heater results in a significantly improved thermal efficiency.

3.7. Conclusions

3.7.1. Constructional re-design

A constructional re-design of a gas fuelled heater was carried out. The working operating principles as identified in chapter 2 have been incorporated in a full detail design.

3.7.2. Prototype

On the basis of the re-design a complete, simplified and operational prototype (type III) was realised.

3.7.3. Assembly

The constructional re-design drastically simplified the assembly of the heater.

3.7.4. Efficiency

Although water was used as a medium instead of a polymer, it may be preliminarily concluded that the thermal efficiency of the heater has significantly increased. Tentatively, the results indicate a rise in thermal efficiency from 41% to 61.5%. Further research is required to validate these first findings under realistic and better controlled conditions.

3.8. Recommendations

Based on the findings, the following recommendations are given.

3.8.1. Testing

Further testing is required to validate the preliminary data on thermal efficiency. It needs an elaborate test set-up at actual operating temperatures of a real polymer extruder to validate these first results.

3.8.2. Discs

The total number of discs installed in the heater required for optimal heat extraction against acceptable costs needs further optimisation.

4. Overall conclusions and recommendations

For the full study presented in this paper, the following conclusions and recommendations can be drawn.

4.1. Conclusions

4.1.1. Thermal re-design

Through the application of new heat extraction and heat transfer principles, is was possible to raise the efficiency of the heater substantially. Alternative operation principles such as fins (increased heat transfer area) and a labyrinth (inducing turbulence) proved to be successful. The overall energy efficiency of the heater was raised from 53.6% (Prototype II) to 66.6% (Segmented Disc design), meeting the pre-set design goal of a thermal efficiency increase of 20% (10% points). The validated concept forms a solid basis for further constructional development and re-design.

4.1.2. Construction re-design

The constructional re-design resulted in a simplified, cheaper and easy to assemble prototype. Based on provisional testing, the overall thermal efficiency of the heater was raised from 41% to 61.5%.

4.2. Recommendations

Further testing is required to validate the preliminary data on thermal efficiency of Prototype III. It needs an elaborate test set-up at operating temperatures on a real polymer extruder to translate the preliminary results into validated results under actual operating conditions.

List of literature

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The Professorship for Polymer Engineering of University of Applied Sciences Windesheim was founded in 2009; the group's objective is to improve the knowledge base on sustainable processing of plastics and composites within and through the higher education system. Its primary function is as a research group in Polymer Engineering, delivering output in the field of applied science. The team operates within market based projects and comprises lectures from Civil Engineering, Industrial Product Design and Mechanical Engineering. The output of the projects is integrated into the cucciculum of these study programmes.

Summary

In the process of injection moulding, molten thermoplastic material is pressed into a mould by means of a heated extrusion screw. Traditionally, the extrusion screw is heated by electric heating coils. Within the context of the "Koenst" research programme a prototype of an injection moulding heater was developed using natural gas as the prime source of thermal energy instead of electricity. In this follow up study, the gas fired prototype was further developed through a thermal and constructional redesign. Through the application of new heat extraction and heat transfer principles, the efficiency of the heater was raised substantially. Ansys-CFX simulations of the new design, featuring perforated segmented disks directly mounted on the extrusion barrel, showed an increased thermal efficiency of more than 20% compared to the original prototype. The findings of the thermal redesign were incorporated into a complete constructional redesign. With the participation of 3Force and Hoekman-Roestvaststaal, a new Segmented Disk Prototype was developed which proved easier to produce and assemble. Basic pre-tests of the prototype indicate an energy efficiency in the range of 61.5%

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