PRELIMINARY RESULTS FROM A NEW CONCEPT FOR FUEL MIXTURE FORMATION AND COMBUSTION IN A DIESEL ENGINE COMBUSTION CHAMBER

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Abstract: *A prerequisite for low CO_2 and pollutant emissions is optimum fuel mixture formation and combustion.*
At the heart of the new fuel induction and combustion system in a diesel engine combustion chamber is the principle of separating the fuel jets in the combustion chamber in such a way as to facilitate a controlled feed of air to the individual fuel jets. This intensifies the mixture of the fuel and air while accelerating the combustion, leading to increased efficiency and reduced pollutant emissions.
The preliminary results from the new system are presented below. First, the optimisation of the combustion chamber and the fuel injection system is described. Then the results achieved on the engine test bed are presented.
*The idea is based on patent specification no.: DE 196 45 913 C2 /**1**/.*

Keywords: new combustion chamber, fuel mixture

1. INTRODUCTION

The expected shortages in fossil resources caused by increasing global mobility are leading to intensified efforts to develop engines which offer greater efficiency and lower emissions, and also to find sustainable energy sources. However, in the short and medium-term there will be no alternative to the internal combustion engine. The combustion engine, including exhaust gas aftertreatment, is therefore the subject of further development efforts aimed at lowering the specific energy consumption and significantly reducing emissions.
Conventional diesel engines work with a recess base combustion chamber and multihole injector nozzles. The fuel induction and combustion requires a pronounced charge action. The injection nozzles are often not arranged symmetrically to the piston recess. The leads to different jet lengths and dispersions. The resulting charge swirl only moves in one direction. This blows the fuel jets into each other. The result is uneven distribution of the fuel in the air. This causes zones with differing fuel concentrations which lead to increased pollutant emissions, especially soot and particle emissions.
The authors have developed a combustion method which clearly separates the fuel jets in the combustion chamber, permitting a controlled feed of air to the individual fuel jets. At the same time an intensive gas movement is created, causing the air to partly penetrate the fuel jets and to partly envelop them.

2. THE NEW COMBUSTION PROCESS

2.1 Structural design

In the new design, there are three or more open radial channels with a specific geometric form in the piston head **Figure 1**. These are extended from the centre of the piston head up to a specified distance from the piston head circumference and evenly distributed around the cylinder axle.

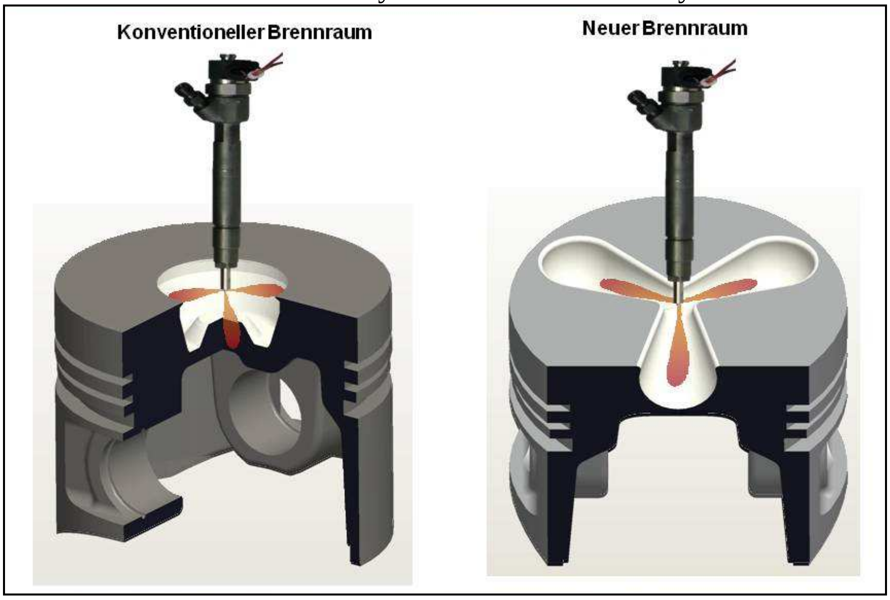

Figure 1: Conventional piston with ω-recess (le.) and piston with new combustion chamber (ri.)

The number of radial channels corresponds to the number of fuel jets, some or all of which penetrate the channels. The arrangement of the radial channels ensures even distribution of the fuel in the combustion chamber. There is a flat area between each of the channels, referred to as the crush zone. During the compression phase this generates the swirl of the working gas. Two opposing air movements (swirls) are formed per channel and fuel jet, and these infiltrate the fuel jet.

2.2 Fuel induction and combustion

In contrast to the conventional recess base combustion chamber, **Figure 1**, the newly designed chamber prevents radial movement of the working gas. Only a tangential charge movement is generated in the combustion chamber, so-called tangential gas movement. The arrangement of the radial channels creates two swirls in each channel; these move in opposing directions. A charge swirl such as that in the recess base combustion chamber, which is created by an elaborate design of the inlet port, is no longer required.

During the compression phase, the swirls reach their maximum intensity around top dead centre. The resulting swirl movement and the collision of the opposing swirls regulates the air and feeds it in an even stream to the fuel jet. This intensifies the mixing of the fuel and air and speeds up the combustion, leading to increased efficiency and reduced pollutant emissions. Air utilisation is also increased at full load.

The direction of the swirl movement reverses during the expansion stroke. The charge now consists of flame gas, hot gas, hot air, fuel droplets, fuel vapour and particles. Two swirls from two adjacent radial channels now collide and infiltrate each other. The mutual infiltration of the hot gas streams intensifies the further fuel mixture and increases the combustion rate, yielding significantly improved combustion **/2/**.

3. OPTIMISATION OF COMBUSTION PROCESS

3.1 Geometric design of the combustion chamber

A large number of parameters need to be adapted to optimise the new combustion process, i.e. to achieve low consumption and to comply with the statutory exhaust gas limits: these range from the geometrical design of the combustion chamber to optimisation of the flow processes, the injection system and the injectors, **Figure 2**.

At the start of the optimisation phase various channel section geometries were drafted and designed with the aid of ProEngineer CAD software.

The CFD software FIRE produced by AVL, Graz, used this data to calculate the air flows and swirl formation and to represent it graphically in video files.

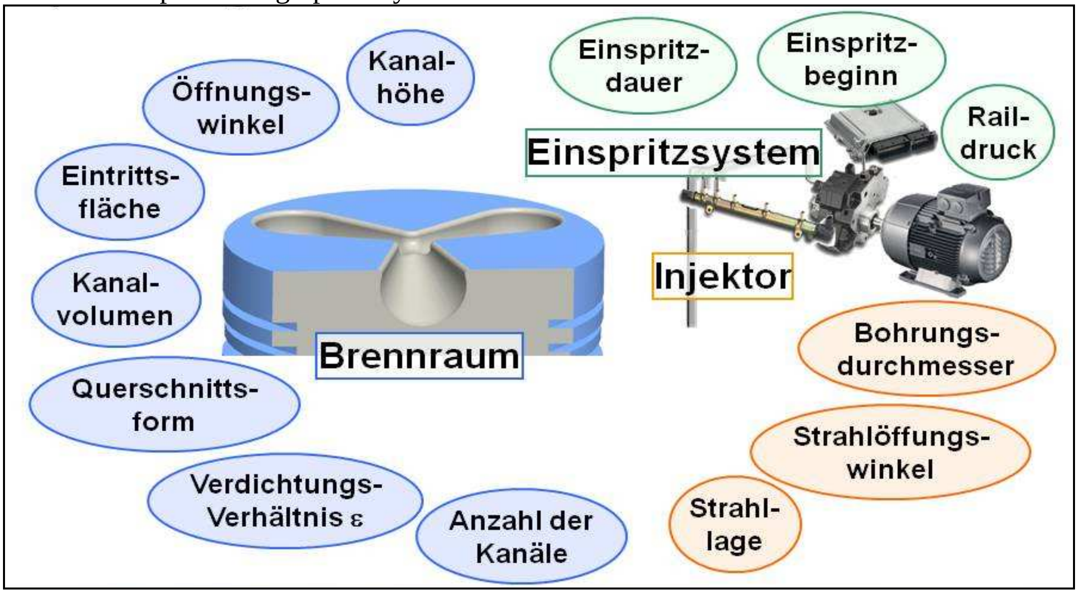

Figure 2: Optimisation parameters

Figure 3 shows four different examples of geometric forms for the channel section. The number of radial channels corresponds to the number of fuel jets. Three radial channels were used in all the present tests.

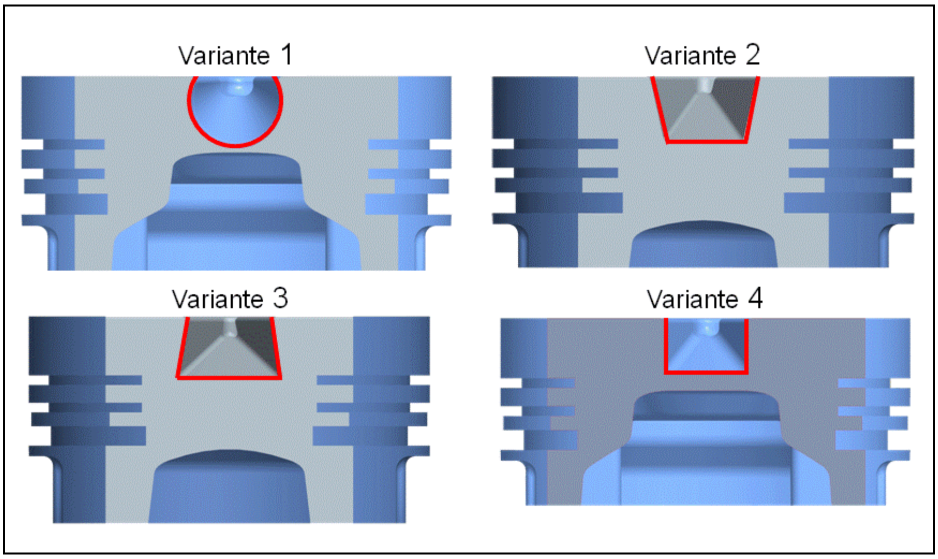

Figure 3: Design of the channel section

The results of the flow calculation are shown in **Figure 4**. As expected, the position and size of the swirl centres differ in each individual geometry. The same applies for the air movement in the channels.

Variant 1 was chosen for production of the "first prototype" and for fitting in the test engine as a result of the favourable position of the swirl centres and the greater air movement. Relatively good exhaust and consumption values were achieved in the "first prototype". For this reason the geometry of the channels was further optimised (Variant W) and recalculated, **Figure 5**.

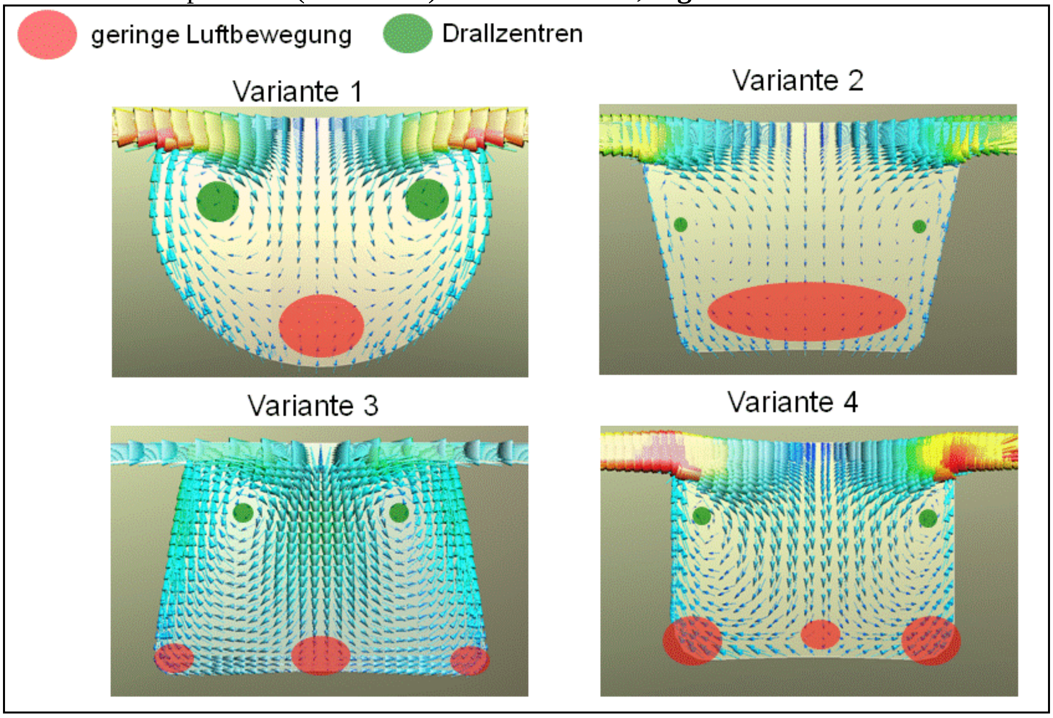

Figure 4: Representation of flow rates in the different channel sections

Calculation of Variant W yielded considerably better results, **Figure 5**. The position of the swirl centres could be shifted towards the fuel jet, which is necessary to obtain optimum fuel mixture. The flow rate could also be increased.

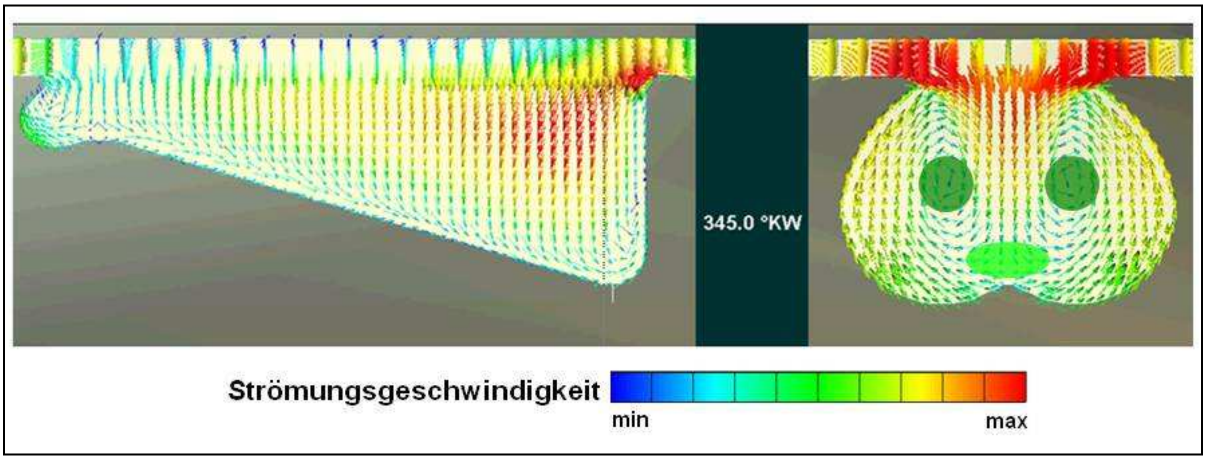

Figure 5: Representation of flow rate of Variant W

The results obtained in the calculation were confirmed by the tests carried out on the engine test bed. Both the exhaust gas emissions and the efficiency were improved in relation to the first prototype.

3.2 Mixture formation and combustion

Besides calculating the flow processes, the FIRE program can also simulate the fuel injection and the arrangement of the injection nozzles. The mixture of fuel and air and the subsequent combustion can also be calculated. These yield significant findings regarding air utilisation in the combustion chamber, the combustion process and accordingly the level of pollutant emissions. The variants were tested on the engine test bed after each optimisation step.

Figure 6 shows the jet position, the droplet distribution and the vaporised fuel in a channel in crank position α_n = 355.5° KW.

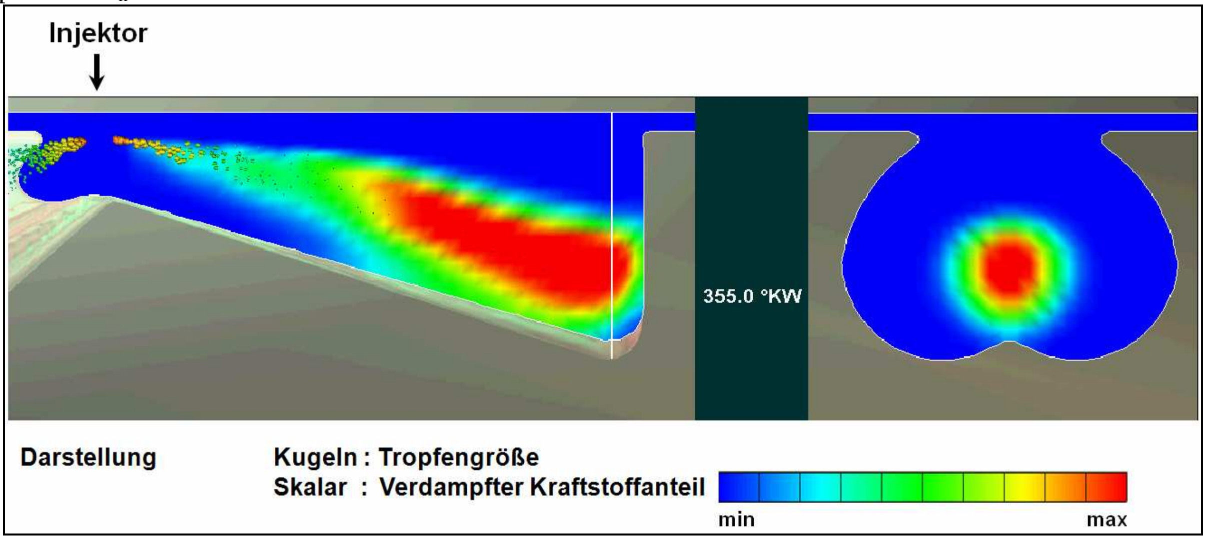

Figure 6: Calculation of the fuel jet

The injection nozzle could be designed with the pre-defined injection pressure and other set parameters. The same nozzle was always used for the tests on the test bed. However, the nozzle needs to be further optimised in order to improve the results.

A precondition for high efficiency and low pollutant emissions is optimum combustion. The optimised air flow and fuel jet are combined in the combustion calculation and recalculated using the combustion algorithms. Here the combustion process is represented on the basis of the gas temperature,

Figure 7.

It is apparent that the temperatures are lower around the centre of the piston. This means that combustion takes place only to an insufficient level in this area, or that the air available is not used in full. This leads, as described above, to the increased pollutant emissions in the upper load range.

The entire optimisation process must be carried out again and the results verified on the test bed to ensure that the set targets can also be reached in the upper load range. Particular attention must be paid here to the area around the centre of the piston.

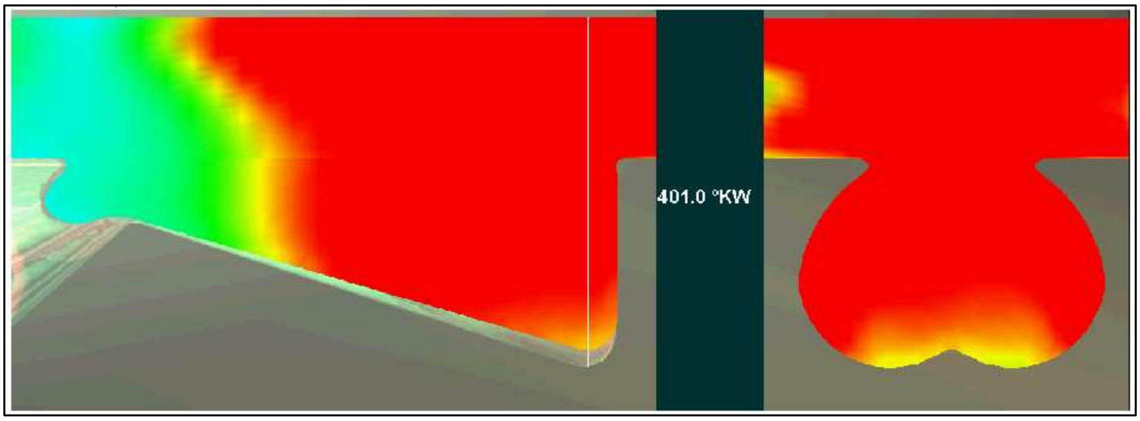

Figure 7: Representation of combustion calculation

4. TESTS CARRIED OUT ON TEST BED

A single-cylinder industrial diesel engine was used for the tests. These engines are not equipped with modern injection systems on account of their simple design, and so the engine was fitted with an externally driven common rail system. This allows all injection parameters to be set as required, **Figure 8**.

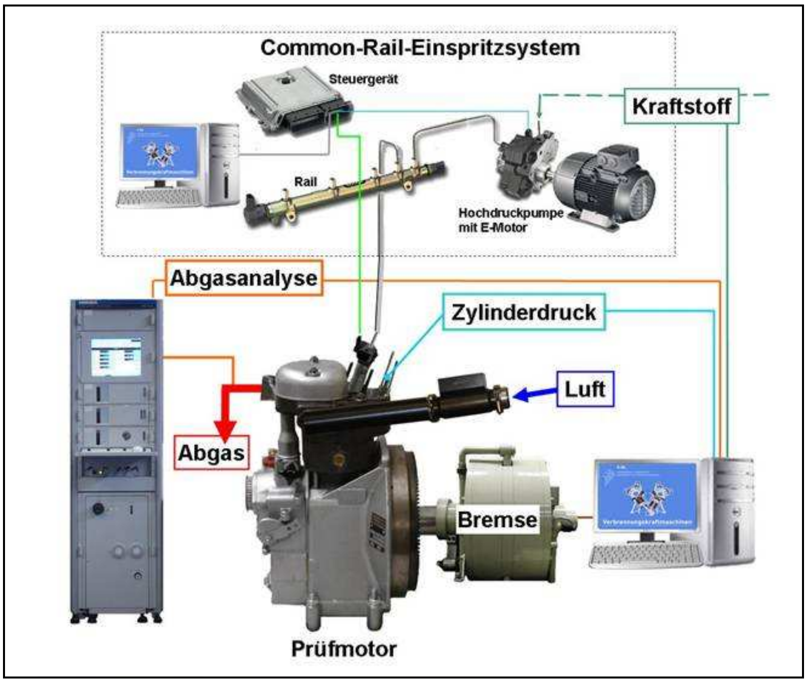

Figure 8: Structure of the test bed

The effect of optimising the injectors and the injector parameters is shown by the cylinder pressure **Figure 9**. The calculated pressures closely match the measured values.

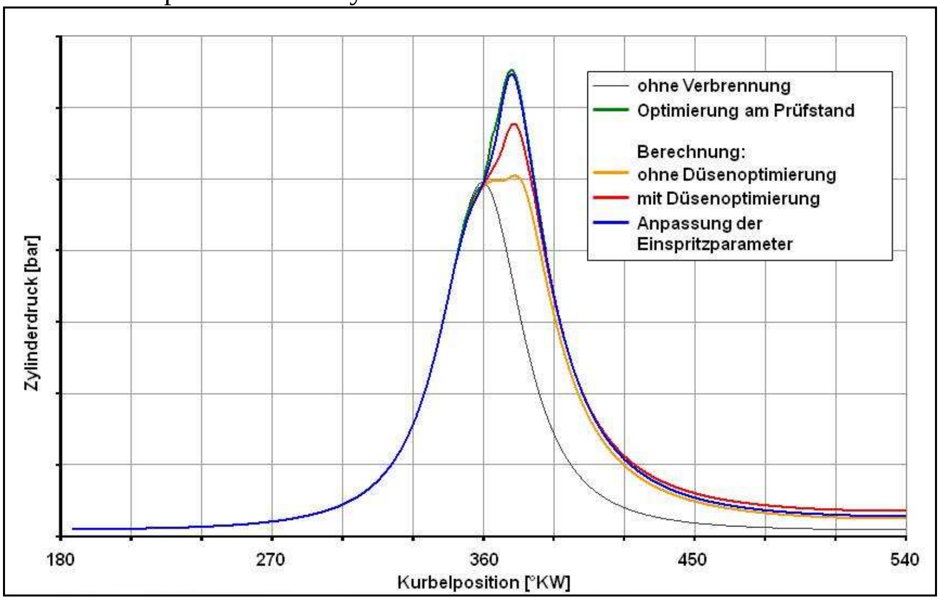

Figure 9: Cylinder pressure comparison (calculation / test bed)

The results of the calculation were largely corroborated by the tests carried out on the engine test bed. Both the exhaust gas emissions and the efficiency were gradually improved in comparison to the "first prototype". In the lower load range, better results were obtained than with the conventional recess base combustion chamber. It was not possible, however, to obtain the expected results in the upper load range, **Figure 10**.

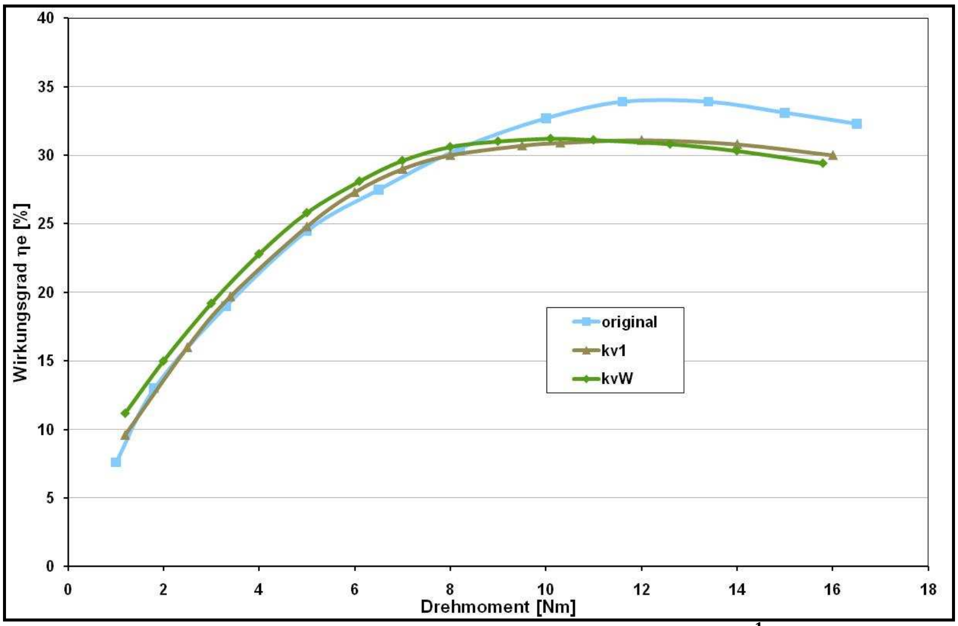

Figure 10: Efficiency at partial load n= 2400 min^{-1}

5. SUMMERY

The development of a new combustion process requires optimisation of the combustion chamber geometry, the flow processes, the injection equipment and the combustion itself. The individual optimisation steps, which were initially calculated and then carried out on the engine test bed, are described. The results obtained are positive but not yet good enough to warrant adaptation of the combustion process in a series-production engine. However the tests also show that there is sufficient potential for the project to be brought to a successful conclusion through further optimisation.

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