IMPROVING THE QUALITY AND UTILISATION OF LOW-VALUE FISH BY PROCESSING

First progress report

Research performed by ATO in the period of Jan 2002 - Dec 2002

Ref.nr. OPD 00/263/030117
Report number: B665

Public Part

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1 Workpackage 3: design and manufacture of a simple low-cost extruder for developing countries

1.1 Designing the extruder

Description of work according to the technical annex:
A simple and low-cost extruder will be designed. The extruder will comprise a diesel engine with gearbox and a stainless steel barrel and die. The extruder will utilise a single screw. An appropriate bearing will be sub-contracted to a local SME for design and manufacture.

In this paragraph first a list with requirements and desired specifications is given. The requirements are further specified in the later paragraphs

Requirements and desired specifications

EXTRUDER	
Number of screws	1
Torque	446 Nm (P/w = 7 kNm/s / 15.7 rad/s)
Rotating Speed	0-150 rpm (= 0 – 15.7 rad/s)
Throughput	5 – 20 kg/h
BARREL	
Length	± 700 mm
Internal diameter	50 mm
Sleeve (grooves)	Longitudinal 1.5 mm deep, 15 grooves
Material (hardness)	Material should be harder than screw material and food grade. (Stainless steel (SS304) hardness 194 Br)
Max. pressure	200 bar
Easy to clean and dismantle	Divide barrel in several elements
SCREW	
Diameter	50 mm
Material (hardness)	Less than hardness barrel and food grade. (Bronze)
Flight	0.5 – 5.0 mm
Pitch	45 mm
DRIVE	
Belt type	V-belts type XPB
Smaller disk	112 mm
Larger disk	335 mm (ratio larger disk : smaller disk = 3:1)
Safety factor	1.3
MOTOR	
Power	Electrical 7 – 10 kW (7 kW = 7 kNm/s)
Voltage	400 VAC
Drive type	V-belt

Table 1: requirements for the extruder under design

1.1.1 Engine and transmission

According to the description of work in workpackage 3, the extruder should comprise a diesel engine with gearbox. However, in consultation with the partners (1st meeting on 25th and 26th March 2002 in Surrey) it was decided to use an electric engine instead of a diesel engine. The main reason for this decision is that an electric engine does not produce the unpleasant gases like a diesel engine does, and therefore it's better to apply, especially for applications inside a building. Instead of a gearbox, a frequency regulator will be used to determine the speed of the engine (more cost efficient, less maintenance).

The most appropriate engines for the kind of extrusion work intended, are engines of 7 to 10 kW. An engine of 9.2 kW, including a safety factor of 1.3, therefore has been selected (see photo 1), although the actual power demand may be less than the maximum engine power. The requirements (among other things) depend on the formulations. Hence the exact requirements for the engine will be determined at the time the tests can be done with the prototype and the given formulations.

For the reduction of the rotating speed from 476 rpm to 150 rpm between engine and the extruder screw, a V-belt system was selected. A V-belt system over a sprocket gear system was opted for, because of its capability to slip at the time the extruder stalls. This way an extra safety is introduced and no harm will be done on mechanical parts. From calculations it is concluded that under normal operations, the belts will not slip. Another reason for using V-belts arises from wear. When using V-belts, the wear taking place is visible and belts can be replaced at the time they become older (or one breaks). When using sprocket gear, wear will continue and one or more sprockets may break. Probably the wheel will be changed too late and other mechanical parts may damage.
The V-belt system consists of two V-belt disks, a small one (diameter 112 mm) on the shaft connected to the motor and a larger one (diameter 335 mm) connected to the screw of the extruder. The V-belt disks are connected by 6 V-belts (XPB-2240). The shaft with the small V-belt disk is connected to the motor by way of a clutch.

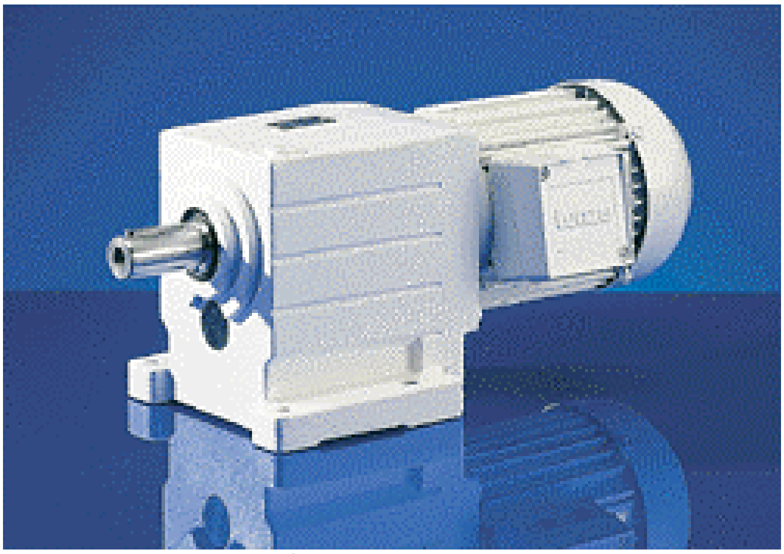

Photo 1: selected engine of 9.2 kW

1.1.2 Bearing

Initially it was planned to sub-contract the design and the manufacturing of the bearing. To save costs, time and complicated calculations, it was preferred to use a standard hub of a car (Toyota Corolla). This hub (see photo 2) is a standard part that is available in Africa as well as in Asia and does fulfil all requirements needed for its function in the extruder. The hub is connected to the larger V-belt disk by using some flanges.

Photo 2: the hub of a Toyota Corolla

Besides the hub, also an axial bearing (51208) (see figure 1) is assimilated in the design. By this bearing all forces caused, as a result of the pressure in the barrel, will be intercept by the barrel and therefore these forces won't charge the frame. The type of axial bearing used is according to the specifications of the manufacturer capable to withstand a force of 46.8 kN. However, this maximum force is given for situations wherein the minimum diameter of the shaft used is 57 mm. The shaft presently used has a diameter of 49 mm. According to calculations (see calculation 1) the maximum axial force in which the bearing could be used under the designed conditions is 22.7 kN, which equals an axial pressure of 121 bar. From experience with different extruders and extrusion processes it is concluded that under the desired applications a pressure of 120 bar will not be reached.

If the pressure unexpectedly rises above 120 bar this bearing will break and the extrusion process will stop, which means that the pressure also will not increase any further. For safety reasons a pressure of 200 bar is used in the rest of the calculations for the other extruder parts. Breaking of the bearing at 120 bar causes that the pressure in the other parts will not reach 200 bar. So, it could be said that this bearing functions as a sort of safety measure. Moreover, since this bearing is cheap and very easy to replace, it is a very desirable safety measure.

The bearing is connected to the extruder frame using a flange.

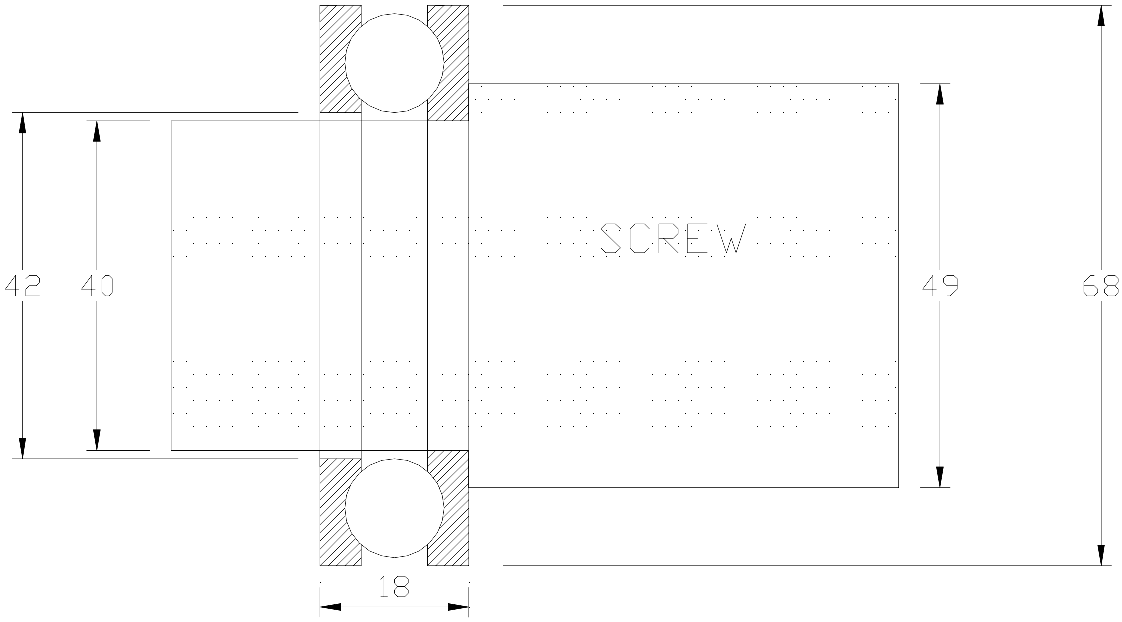

Figure 1: schematic drawing of the position of the screw in the axial bearing (in present design)

Calculation 1:

<u>*Situation according to the data of the manufacturer:*</u>
D_{in} = 40 mm (diameter of screw in the bearing)
D_{ex1} = 57 mm (diameter of screw outside the bearing, the part that presses against the bearing)
F_{max} = 46800 N (maximum force)

$A = \pi/4 \cdot (D_{ex1}^2 - D_{in}^2)$ (area in mm^2)
$\sigma_{max} = F_{max}/A$ (pressure in N/mm^2) N/mm^2 = MPa

Using the parameters of the manufacturer, the next value for the maximum pressure could be determined:

$\sigma_{max} = 46800/(\pi/4 \cdot (57^2 - 40^2)) = 36.13$ MPa

<u>*Present situation:*</u>
D_{in} = 40 mm
D_{ex2} = 49 mm
σ_{max} = 36.13 MPa (calculated, see above)

$F_{max} = \sigma_{max} \cdot A = 36.13 \cdot (\pi/4 \cdot (49^2 - 40^2) = 22730$ N

Maximum allowable pressure in the extruder = $F_{max} / (\pi/4 \cdot D_{ex2}^2)$ = 12.1 MPa = 121 bar

The shaft, which is connected to the motor by way of the clutch, is supported by two bearings. One of type SNL 509TC and one of type SNL 508-607. For thermal expansion reasons one bearing is forced to the shaft (SNL 509TC) while the other bearing allows some slicing through the bearing.

1.1.3 Barrel

The total barrel length is approximately 700 mm. It was decided to divide the total barrel into 5 segments; 4 barrel segments and 1 pre-die segment. The two main reasons for this decision were cleaning and wear. Smaller parts can be more easily and thoroughly cleaned, and this way only one segment of the barrel can be replaced instead of the whole barrel when only part of the barrel is damaged. To connect the different barrel segments standard flanges are used.

Because of the desired application, the internal side of the barrel has to be made of a food grade material. Another demand to the material is that the hardness of the barrel and screw material should differ, ensuring wear taking place at only one of the two parts. Preferably, the material used for the barrel should be harder than the material used for the screw. Therefore, stainless steel was selected as barrel material and bronze for the screw. To save costs, a sleeve will be made into the barrel. This sleeve is easy to change and in this situation only the sleeve has to be made of food grade stainless steel (SS 304). The rest of the barrel can be made of cheaper steel (steel 52). Out of calculations it is concluded that by the most critical situation (internal pressure 200 bar and barrel thickness of 9 mm) steel 52 gives efficient protection.

To improve the friction between the wall of the sleeve and the screw, several grooves will be made into the sleeve. At the end of every barrel segment the grooves must be rubbed out to avoid bad material flow between two barrel segments.

The first segment is the feeding segment or the inlet. The first segment has a length of 225 mm. To avoid nasty gases at the inlet and back flow of the product in the extruder it is necessary to cool the inlet section. Water will be used to cool the segment. The material used for manufacturing the shells is steel 35.

The next two segments are equal. The length of each segment is 150 mm. In contrast to the first segment, these two segments do not have a cooling system. For the application intended, it will not be necessary to cool these segments of the extruder. To make direct expanded products the temperature of the sample must be high (over 100 °C) when leaving the extruder and therefore it’s necessary to heat the sample by heating the barrel segments. For heating the barrel segments Mickenhagen ceramic heating bands of the type KHB24 (230V, 2 kW) are applied. Also for making snack like products it could be necessary to heat the barrel segments. The exact necessary requirements will be determined by experiments done with the prototype.

The main part of the last segment of the barrel is similar to segments 2 and 3. The only difference is that the last segment is provided with a cooling system as well as a heating band. Depending on the product one likes to produce, heating or cooling of the last segment may be required. Most likely for the production of direct expanded products it would be necessary to heat the last segment, while cooling the last segment may be needed for the production of snack like products.

The barrel segments are mutually connected with 4 M16 bolts of the material SS8.8. These bolts can withstand a maximum stress of 72 kN. From calculations it follows that the stress at the bolts and nuts during the worst case situation will be 21 kN.

To control (measure) the temperature in the barrel segments 2, 3 and 4, the barrel segments contain an insert to place a temperature-measuring sensor (Dynisco TB422J-6/18-0-0-1).

1.1.4 Screw

To determine the right configuration of the screw, experiments have been conducted with a single screw extruder comparable to that one under design. These experiments were done with different mixtures of fish and flour. Two different screw configurations (see photo 3) were tested for producing snack like products (pellets) as well as direct expanded products. From experience with different extruders and extrusion processes it is concluded that for making direct expanded products it is best to use a screw configuration with a relative large pitch and a strong compression at the end of the screw (see photo 3 screw 2). However, for producing snack like products a screw configuration with a smaller pitch and no compression is generally used (see photo 3 screw 1).

Photo 3: examples of extrusion screws

From the experiments it is concluded that by using screw number 1 (see photo 3) no direct expanded products could be made. Using screw number 2 (photo 3) gives the possibility to produce snack like products as well as direct expanded products. The pitch of this screw configuration was relative large (45 mm) and also constant. Seen the fact that manufacturing of a screw with a constant pitch is much easier and cheaper than manufacturing a screw with a variable pitch and the possibility to produce snack like products as well as direct expanded products with the same screw, screw configuration number 2 was chosen for the extruder under design.

The hardness of the material of the screw must be softer than the material of the barrel (sleeve) to prevent destructive wear of the barrel and the screw. In consultation with the partners it is decided to use bronze as the material for the screw. Bronze is softer than stainless steel (which is used for making the sleeve), is easy to process, is food grade and is available in Africa as well as in Asia.

There are two possibilities to dismantle the screw: 1) to remove it via the backside or 2) to remove it via the front side. Seen the application and the screw configuration, the greatest change in which the extruder will get stuck, is when the extrusion material accumulates at the end (near the die) of the extruder. In that case it is better to remove the screw at the front instead of the back. Accordingly, you do not have to transport the whole screw with the accumulated material through the whole barrel, but just several centimetres. At this moment the apparatus for dismantling the screw is under design.

1.1.5 Die

The die does greatly affects the final extrusion product. Different dies are required for snack like products and direct expanded products. Seen the desired flexibility of the extruder under design it is necessary to design a system in which the die can be easily changed. The invented system consists of two parts: 1) the pre-die, which is connected to the last barrel element with the same flange used to connect the barrel parts mutually, and 2) the final die, which is inserted in the pre-die by means of screw thread. The final die is easy to change and also easy to manufacture. To control (measure) the pressure and the temperature in the pre-die, the pre-die contains an insert to place a combined pressure and temperature-measuring sensor (Dynisco TPT463E-5M-6/18).

In paragraph 2.2 some results of extrusion experiments with a single screw extruder comparable to that one under design and different dies are shown.

1.1.6 Frame

The frame is designed to be constructed in the so-called C-form. In this construction the barrel is located above the motor. Typical for this kind of construction is the compact and stabile form. The tip over effect in this construction is nil.

A standard U-profile of steel will be used to construct the frame. From calculations it is concluded that the designed frame made from this U-profile gives efficient resistance. For

preventing some dangerous vibrations caused by the extrusion process in total, the frame is equipped with 6 rubber feet.
The hub is connected to the frame by way of a U-beam.To connect the barrel to the frame a trestle will be used.

1.1.7 Overall extruder

Figure 1 in the ANNEX shows the overall extruder. Figure 2 in the ANNEX shows several critical points. These critical points are numbered from 1 to 10. The frame of figure 2 is not correct!

The critical points indicated are:

1) Strength of barrel
2) Strength of bolts for connecting barrel
3) Axial load at the bearing (see also calculation 1 in paragraph 1.1.2)
4) Torsion in the screw
5) Shear in bolts between flange and hub
6) Shear in bolts between flange and large V-belt disk
7) Selection of V-belts and disks
8) Torsion of main shaft (axis)
9) Selection of bearings
10) Selection of clutch (coupling)

Calculations for the selection of suitable parts show that the design fulfil the requirements needed for the intended extrusion processes.

1.2 Input partners developing countries

The most important requirements for the extruder to develop were agreed during the first meeting on 25th and 26th March 2002 in Surrey. The missing requirements were discussed via e-mail. Also the possibility to manufacture the designed extruder parts and to construct the extruder in the developing countries was discussed via email.

1.3 Manufacture of the extruder

ATO has started to manufacture the prototype. According to the planning this prototype will be available at the end of February. At that moment some tests and some adjustments, if necessary, will be done. The prototype will be demonstrated during the next project meeting (April 2003) at ATO.

2 Workpackage 4: extrusion and drying of low-value fish combined with other local crops

2.1 Product Formulation

Description of work according to the technical annex:
Lean or fatty low-value fish will be mixed with local commodities such as rice, soya flour, maize, millet, tapioca, palm oil and fish oil to provide nutritious and organoleptically acceptable products. Products, particularly infant weaning foods will be designed with FAO and EU nutritional guidelines.

2.1.1 Extrusion of direct expanded products and snack like products

Some experiments were performed with a single screw extruder comparable to the one under design to test the possibility of making direct expanded products and snack like products out of various mixtures of flour and fish. For these mixtures the next raw materials were used:
1) Tapioca flour with a water content of 12.2%
2) Maize grits with a water content of 11.2%
3) Hake filet (*Merluccius merluccius)* with a water content of 80.5%
4) Nile perch filet *(Lates niloticus)* with a water content of 79.0%

The next mixtures were tested for its possibility to produce snack like products as well as direct expanded products.

Mixture	Tapioca (%)	Maize (%)	Hake (%)	Nile Perch (%)	Snack like*[1] (- - - tot +++)	Direct expanded*[1] (- - - tot +++)
1	80		20		+/-	- - -
2	70		30		+	- -
3	60		40		++	-
4	35	35	30		++	+/-
5	32	32	36		+++	+/-
6	10	60	30		++	+
7		70	30		+	++
8		60	40		++	++
9		55	45		+++	+++
10		55		45	+++	+++
11		60		40	++	++
12	60			40	++	-

*[1] increasing scale (- - -, - -, -, +/-, +, ++ and +++). - - - indicates not suitable, +++ indicates very good suitable.

Table 2: tested mixtures for producing snack like products and direct expanded products

From the results shown in table 2 it can be concluded regarding producing snack like products:
1) Producing snack like products is possible with both tapioca and maize in combination with Hake or Nile Perch.
2) In general there is no difference in result between products made using Hake or Nile Perch.
3) A mixture of tapioca with maize shows better results than the ones using only tapioca or maize.
4) Increased fish content (between 20 and 45%) leads to better extrusion products.

For the direct expanded products can be concluded that:
1) Maize is needed for making good expanded products. Products with only tapioca and fish do not expand well.
2) In general there is no difference in result between products made using Hake or Nile Perch.

3) Mixtures with only maize and fish show a greater expansion than mixtures of maize and tapioca with fish.
4) Increased fish content (between 20 and 45%) leads to better extrusion products.

2.2 Extrusion cooking of mixtures

Description of work according to the technical annex:
Extrusion processing parameters including temperature, pressure, screw speed and product expansion ratio will be measured and adjusted for optimum products.

2.2.1 Extrusion of direct expanded products

Some experiments were performed with a single screw extruder comparable to the one under design to determine the effects of several parameters on the extrusion product. These experiments were done with mixtures of maize grits and minced hake filet *(merluccius merluccius).* In table 3 the results of these experiments are shown. From these results the following can be concluded:

1) The expansion rate increases when the diameter of the die becomes smaller
2) The expansion rate increases when the throughput decreases. This effect is smaller than the effect of the diameter of the die.
3) The required power (amperage) increases when the throughput increases.
4) The screw speed (rpm) does significantly affect the expansion rate.
5) The effect of temperature on the expansion rate is not clear. Because of friction between the material and the barrel the material will warm up. The combined heat caused by this friction and externally heat imposed by heating bands induces the final product temperature. From experience with other extrusion processes it follows, that the product temperature does affect the expansion rate. So, in future experiments the product temperate should also be measured to determine the effect of temperature on the expansion rate.

Sample	Flour/ fish*[1]	Die (mm)	Temp 1 (°C)	Temp 2 (°C)	Speed (rpm)	Amperage (A)	Expansion (%)	Throughput (g/min)
250602-3	80/20	8.5	88	82	140	5	160	
250602-4	80/20	8.5	89	83	180	5	170	
080702-1	70/30	4.0	85	72	160	7	240	238
080702-2	70/30	4.0	90	71	160	7	230	238
080702-3	70/30	4.0	92	71	180	7	230	238
080702-4	70/30	4.0	91	71	180	8	210	373
100702-1	70/30	4.0	83	89	160	8	330	175
100702-2	70/30	4.0	85	92	160	10	310	281
100702-3	70/30	4.0	84	87	160	12	300	422
100702-4	70/30	4.0	85	85	180	11	300	426
100702-5	70/30	4.0	95	81	160	12	300	425
100702-6	70/30	4.0	98	81	160	8	330	182
100702-7	60/40	4.0	86	97	160	8	320	128
100702-8	60/40	4.0	81	93	160	9	290	272
100702-9	60/40	4.0	82	90	180	9	300	272
100702-10	60/40	4.0	84	88	140	9	300	272
100702-11	60/40	4.0	90	86	180	6	310	272

*[1] flour: maize grits with water content of 11.2%; fish: mince of hake filet with water content of 80.5%

Table 3: extrusion parameters of the extrusion of direct expanded products.

Photo 4 shows a direct expanded extrusion product of maize grits and hake filet. Further research at the extrusion of direct expanded products consisting out of fish and flour will be done with the prototype and desirable raw materials.

Photo 4: a direct expanded extrusion product consisting out of maize and hake.

2.2.2 Extrusion of snack like products

Some experiments were performed with a single screw extruder comparable to the one under design to determine the effects of several parameters on the extrusion product. These experiments were done with mixtures of maize grits, tapioca flour and minced hake filet *(merluccius merluccius).* In table 4 the results of these experiments are shown. From these results the following can be concluded:

1) The total expansion rate (is expansion rate after deep-frying) increases when the die diameter decreases.
2) At the given relative low extrusion temperatures, the die diameter does not have a great effect on the direct expansion rate.
3) The expansion rate increases when the throughput decreases. This effect is smaller than the effect of the diameter of the die.
4) The required power (amperage) increases when the throughput increases.
5) The screw speed (rpm) does significantly affect the expansion rate.
6) The effect of temperature on the expansion rate is not clear. Because of friction between the material and the barrel the material will warm up. The combined heat caused by this friction and externally heat imposed by heating bands induces the final product temperature. From experience with other extrusion processes it follows, that the product temperature does affect the expansion rate. So, in future experiments the product temperate should also be measured to determine the effect of temperature on the expansion rate.

Sample	Flour/ fish*1	Die (mm)	Temp 1 (°C)	Temp 2 (°C)	Speed (rpm)	Through-put (g/min)	Ampe-rage (A)	Expansion (%)	Deep-fry time*2 (s)	Expansion total (%)
170702-1	67/33	3	50	72	100		5	190	50	330
170702-2	67/33	3	51	71	100	125	4	160	40	230
170702-3	67/33	3	49	69	100	240	4	120	30	170
170702-4	67/33	1	56	80	100	221	14	110	11	350
180702-1	67/33	4	74	70	100	197	4	140	70	270
180702-3	67/33	4	69	68	100	240	5	140	50	220
180702-4	67/33	1	77	96	100	100	8	150	11	390
180702-5	67/33	1	77	98	100	200	11	160	10	360
180702-6	67/33	1	77	97	100	250	12	150	10	380
260702-1	69/31	3	68	69	100	195	7	150	55	260
260702-2	69/31	3	71	71	130	198	6	160	60	300
260702-3	69/31	1	75	94	100	120	10	130	17	440
260702-4	69/31	1	74	94	100	50	7	140	17	370
260902-1	63/37	1*3	69	82	120	106	5	140	30	370
260902-2	63/37	1*3	70	82	160	106	5	140	23	370
260902-3	63/37	1*3	68	83	160	222	6	150	27	370
260902-4	63/37	1*3	69	85	160	258	7	150	32	440
260902-5	63/37	1*3	70	79	100	106	5	150	30	380

*1 flour: maize grits with water content of 11.2% and tapioca flour with water content of 12.2%; fish: mince of hake filet with water content of 80.5%. All experiments were done with a mixture of flour consisting out of 50% tapioca and 50% maize.
*2 deep-fry temperature 192 – 197°C
*3 sheet die with height of 1 mm and width of 11mm

Table 4: extrusion parameters of the extrusion of direct expanded products

Photos 5 and 6 shown an extruded snack like product of maize grits and hake filet before (left) and after (right) deep-frying. Further research at the extrusion of direct expanded products consisting out of fish and flour will be done with the prototype and desirable raw materials.

Photo 5: extruded snack like product consisting out of maize and hake before and after deep-frying.

Photo 6: extruded snack like product consisting out of maize and hake before and after deep-frying

ANNEX; overall drawings of the designed extruder

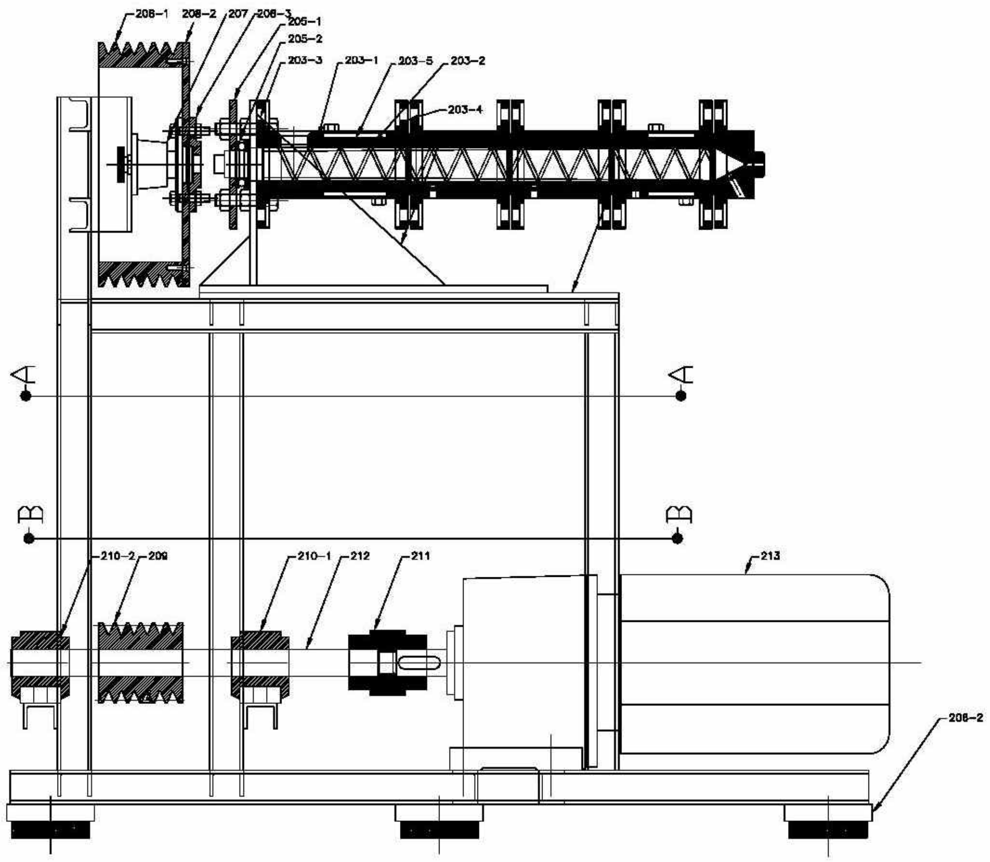

Figure 1: schematic overview of the extruder

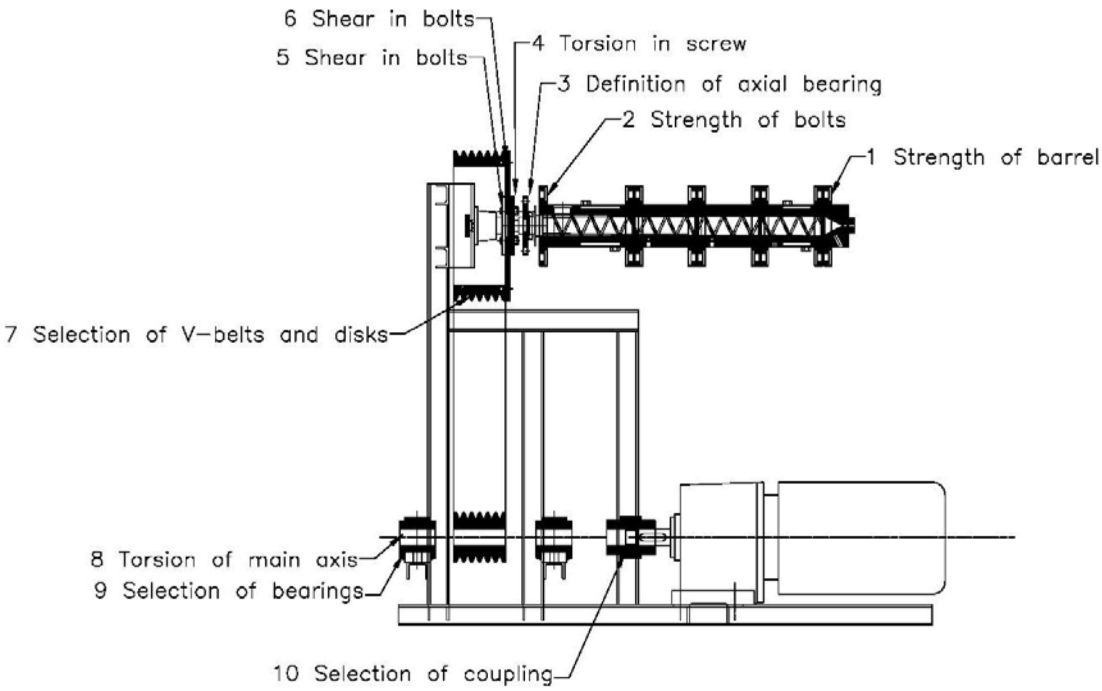

Figure 2: Overview of the critical points