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Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: AN EXTRUDER AND A METHOD OF EXTRUDER OPERATION

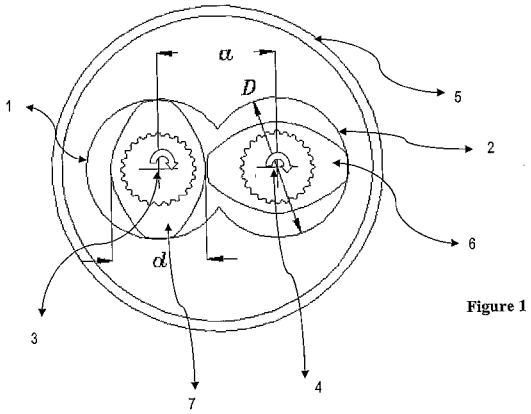


Figure 1

(57) **Abstract**: The invention relates to a method of extruder operation; the extruder comprising a housing having at least two cylindrical housing bores, each housing bore having an axis disposed parallel to the other axis and the first and second axes separated by a distance "a"; at least a first screw shaft and a second screw shaft being disposed in the first and second housing bores; the first and second screw shaft being provided with a first and second screw respectively; the first and second screw each having an extruder diameter D and a screw root diameter d; the first and second screw shaft each having a volumetric ratio of at least 1.4 wherein the volumetric ratio is defined by the extruder diameter D divided by the screw root diameter d; at least two inlet hoppers being provided in the vicinity of the housing bores and opening into said housing bore with at least one of the inlet hopper having a side inlet into the housing bore; the method comprising: feeding material to be processed through the at least two inlet hoppers into the housing bores; conveying the material through the extruder length from the inlet hoppers to the extruder outlet; driving each of said first and second screw shafts at a speed of at least 11000pm and at a torque density of at least 8.5 Nm/cm^3; the torque density defined by the shaft torque at each first and second shaft divided by the third power of the distance 'a' of the first and second axis.

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The invention relates to twin screw extruders and particularly to a method of operation of a twin screw extruder with shafts rotating in the same direction.

BACKGROUND

Twin screw extruders having a feed opening at one end and a discharge opening at the other end are well known and extensively used for specific purposes of mixing materials which includes kneading, dispensing, homogenizing, distributing a material with or without increase in temperature or heat input in a continuous and controlled manner. Material is fed to the extruder by a hopper connected at the inlet and the extruder is typically operated on the so called 'starve feeding' methodology.

The material may consist of a single constituent or ingredient or multiple constituents in one phase or more phases. Some constituents may need to undergo phase transformation during processing. The work that is done by the extruder is the result of applications of forces that cause shearing action in various planes, compression, elongation and folding. It is desirable that these forces are applied uniformly on every particle or molecule only for a specific period of time in order to limit the work done as excessive work will cause fragile molecules to disintegrate resulting in a degraded product. The extent of work done is dependent on a number of factors including nature of the material being processed, amount of material that the extruder can receive as input at various ports, amount of torque available at any given speed, length of the extruder, and configuration of the extruder processing zone elements and components.

It is believed that an increase in shear rate enhances the quality of mixing and homogenization, though an increase in shear rate results in an increase in the specific energy requirements and temperatures. To balance this increase in the specific energy requirements and temperatures, it is essential to reduce the dwell time within the extruder and increase the through put. One approach has been the increasing of the volumetric ratio of the extruder and also by significantly increasing the minimum specific torque requirements. The volumetric ratio of an extruder is defined as the ratio of the extruder diameter [D] divided by the root diameter of the screw [d]. An increase in the volumetric ratio increases the fill capacity of the extruder though adversely affects the torque carrying capacity. The specific torque [T/a^3] of an extruder refers to the ratio between the torque [T] and the third power of the center distance between the two axes [a] of the twin screw extruder. To increase the specific torque requirements a higher powered motor is required which requires corresponding strengthening of other components inside the gearbox and the torque transmitting system. The increase in volumetric ratio and specific torque requires various modifications involving a combination of design, materials, treatment and higher levels of safety.

SUMMARY

The invention relates to a method of extruder operation; the extruder comprising a housing having at least two cylindrical housing bores, each housing bore having an axis disposed parallel to the other axis and the first and second axes separated by a distance "a"; at least a first screw shaft and a second screw shaft being disposed in the first and

second housing bores; the first and second screw shaft being provided with a first and second screw respectively; the first and second screw each having an extruder diameter D and a screw root diameter d ; the first and second screw shaft each having a volumetric ratio of at least 1.4 wherein the volumetric ratio is defined by the extruder diameter D divided by the screw root diameter d; at least two inlet hoppers being provided in the vicinity of the housing bores and opening into said housing bore with at least one of the inlet hopper having a side inlet into the housing bore; the method comprising: feeding material to be processed through the at least two inlet hoppers into the housing bores; conveying the material through the extruder length from the inlet hoppers to the extruder outlet; driving each of said first and second screw shafts at a speed of at least 1000rpm and at a torque density of at least 8.5 Nm/cm^3; the torque density defined by the shaft torque at each first and second shaft divided by the third power of the distance 'a' of the first and second axis.

The invention also relates to a method of extruder operation; the extruder comprising a housing having at least two cylindrical housing bores, each housing bore having an axis disposed parallel to the other axis and the first and second axes separated by a distance "a"; at least a first screw shaft and a second screw shaft being disposed in the first and second housing bores; the first and second screw shaft being provided with a first and second screw respectively, each screw including at least one element; the first and second screw each having an extruder diameter D and a screw root diameter d; the first and second screw shaft each having a volumetric ratio of at least 1.4 wherein the

volumetric ratio is defined by the extruder diameter D divided by the screw root diameter d_r; a first intake element coupled to the first shaft and including a first flight, a second intake element coupled to the second shaft adjacent the first intake element and including a second flight, wherein the first flight and the second flight are adapted to co-operatively create a positive conveying effect to convey material when the first intake element and the second intake element are rotated in the same direction; at least two inlet hoppers being provided in the vicinity of the housing bores and opening into said housing bore with at least one of the inlet hopper having a side inlet into the housing bore; the method comprising: feeding material to be processed through the at least two inlet hoppers into the housing bores; conveying the material through the extruder length from the inlet hoppers to the extruder outlet; driving each of said first and second screw shafts at a speed of at least 1000rpm and at a torque density of at least 8.5 Nm/cm^3; the torque density defined by the shaft torque at each first and second shaft divided by the third power of the distance 'a' of the first and second axis.

BRIEF DESCRIPTION OF ACCOMPANYING DRAWINGS

The accompanying drawings illustrate the preferred embodiments of the invention and together with the following detailed description serve to explain the principles of the invention.

Figure 1 illustrates the geometry of a twin screw extruder with both shafts moving in the same direction.

Figure 2 illustrates a plan view of a twin screw extruder in accordance with an embodiment of the invention.

Figure 3: illustrate a side view of a twin-screw extruder in accordance with an embodiment of the invention.

Figure 4: illustrates a cross sectional view of the twin screw elements that provide increased intake capacity, in accordance with an embodiment.

Figure 5: illustrates the undercut formed by the flight of a screw element in accordance with an embodiment.

DETAILED DESCRIPTION

In the following description, for purpose of explanation, numerous specific details are set forth in order to provide an understanding of the various embodiments. It will be evident, however, to one skilled in the art that the various embodiments may be practiced without these specific details. It will be appreciated that the various embodiments discussed herein may or may not be the same embodiment, and may be grouped into various other embodiments not explicitly disclosed herein.

It will be understood by those skilled in the art that the foregoing general description and the following detailed description are exemplary and explanatory of the invention and are not intended to be restrictive thereof. Throughout the patent specification, a convention employed is that in the appended drawings, like numerals denote like components.

A method of extruder operation is disclosed for a twin screw extruder. With reference to figure 1, the cross section of the extruder as shown has housing (5) that includes two cylindrical housing bores (1, 2) having parallel axes (3, 4) respectively. Each bore houses a screw shaft that supports a screw (6, 7) that is formed of processing elements. The two shafts are placed parallel to each other with their centre distance between the axes 'a'. Each element on one shaft while maintaining continuity with the adjacent element on the same shaft has a corresponding conjugate element on the other shaft.

The extruder in accordance with an aspect of the invention has at least two hoppers for feeding material to the extruder. At least one side hopper is provided to feed additional material to the extruder. With reference to figure 2, the inlet of the extruder in accordance with an embodiment of the invention is illustrated having a plurality of hoppers (10, 11, and 12) for feeding material to the extruder. In the embodiment illustrated, the existing hopper (11) positioned vertically above the extruder at the inlet is supplemented with side hoppers (10 and 12). In accordance with another embodiment, the at least two hoppers may include hoppers (10, 12) both provided at the side of the extruder.

Figure 3 illustrates an extruder in accordance with an embodiment having one side hopper (14) with force feeding means (13) that supplements the intake capacity of the hopper (15) for feeding material to the extruder.

In accordance with an embodiment, one hopper may be force fed while one hopper is gravity fed. Alternatively, both hoppers may be force fed to achieve the desired feed rate into the extruder. In the embodiment illustrated in figure 2, the side hoppers (10 and 12) are force feeding material to the extruder. The provision of the additional hopper and side inlets allows for a greater feed input into the same sized extruder.

The method of extruder operation provides for side feeding the extruder at least at the inlet end of the extruder. Side feeding the extruder at the inlet allows the extruder to run at the feed rate determined by the available torque in the extruder. The method of side feeding the extruder in the manner as described herein allows complete control over the amount of material that the extruder can receive at lower diameter ratios and lower specific torque levels.

The method of extruder operation as described requires the extruder to have a volumetric ratio of at least 1.4 wherein the volumetric ratio is defined by the extruder diameter D divided by the screw root diameter d. The extruder includes at least two inlet hoppers being provided in the vicinity of the housing bores and opening into said housing bore with at least one of the inlet hopper having a side inlet into the housing bore. Material is to be fed to the extruder through these hoppers including the at least one side hopper. The method also requires that each of said first and second screw shafts are driven at a speed of at least 1000rpm and at a torque density of at least 8.5 Nm/cm^3.

In accordance with another aspect of the invention, the extruder uses elements for the twin screws that provide a positive conveying effect.

With reference to figure 4, an extruder in accordance with an embodiment is illustrated having two cylindrical housing bores (1, 2). The extruder includes a first shaft (16) and a second shaft (18) with a first intake element coupled to the first shaft and including a first flight (17) and a second intake element coupled to the second shaft and including a second flight (19).

Undercuts (32) are defined by the flights (f) of the first and second elements as illustrated by figure 5. The first flight and the second flight both define an undercut. The undercut allows the intake elements to plough the material through the extruder system and create a positive conveying effect when run at or above a particular speed. The intake elements preferably have a single flight, but may alternatively have more than one flight. In an axial cross-section of the flights, the size and shape of the undercut preferably makes an acute angle to the axis of the intake elements. Typically, single flight intake elements of conventional extruder systems have an angle of 90 degrees or higher under the flight of the intake element. The intake elements of the preferred embodiment, however, preferably have a less than 85 degree angle and more preferably a 75 degree angle to create the undercut.

The method of extrusion in accordance with an aspect requires elements as described above to be used in the extruder that is run at a speed of at least 1000 rpm. In addition the volumetric ratio of the extruder is at least 1.4 and the extruder is fed by at least one side inlet. This method of operation significantly reduces operating costs while providing the desired shear rates and through put.

A 21.1mm center distance extruder with a number of D/d ratios ranging from 1.27 to 1.89 is studied for volumetric capacity and maximum possible power at prescribed specific torque, and results of the study are tabulated in Table 1. Based on this information, mean residence time is calculated at 50% degree of fill and the results of this calculation are tabulated in Table 2. Generally applications are torque limited and residence time is calculated for D/d = 1.4 and 1.49 and compared with D/d = 1.55 and 1.71. With an increased mean shear intensity (D/f), the residence time is comparable at lower specific torque.

By the use of special elements as explained in the previous section, further control over the extrusion can be achieved for extruder with D/d > 1.4, by overcoming feed limitation as well as achieving higher torque limited outputs that substantially exceed outputs of D/d > 1.5 extruders as shown in Table 3.

INDUSTRIAL APPLICABILITY

The method provides for higher throughput machines with greater torque carrying capability. The method does not demand design restrictions and allows for smaller sized machines to deliver higher throughput without comprising on mixing efficiency, thereby providing reduction in floor space requirement and ease of operability. The elements as described above along with the additional side feeding overcome feed limitations of the extruder and allow for greater throughputs without requiring an increase in volumetric ratio or in the torque density requirements.

The method also allows to use extruders with the highest torque densities with specific torque of 17 Nm/cm^3 and higher. As a result of this, higher outputs, a better product quality and better utilization of resources will result.

We claim:

1. A method of extruder operation; the extruder comprising

a housing having at least two cylindrical housing bores, each housing bore having an axis disposed parallel to the other axis and the first and second axes separated by a distance "a";

at least a first screw shaft and a second screw shaft being disposed in the first and second housing bores; the first and second screw shaft being provided with a first and second screw respectively; the first and second screw each having extruder D and a screw root diameter d; the first and second screw shaft each having a volumetric ratio of at least 1.4 wherein the volumetric ratio is defined by the extruder diameter D divided by the screw inner diameter d;

at least two inlet hoppers being provided in the vicinity of the housing bores and opening into said housing bore with at least one of the inlet hopper having a side inlet into the housing bore;

the method comprising:

feeding material to be processed through the at least two inlet hoppers into the housing bores;

conveying the material through the extruder length from the inlet hoppers to the extruder outlet;

driving each of said first and second screw shafts at a speed of at least 1000rpm and at a torque density of at least 8.5 Nm/cm^3; the torque density defined by the shaft torque

at each first and second shaft divided by the third power of the distance 'a' of the first and second axis.

2. A method as claimed in claim 1 wherein material is fed into the extruder from at least one side hopper.

3. A method as claimed in claim 3 wherein the material is force fed from a side hopper into the extruder.

4. A method of extruder operation; the extruder comprising

a housing having at least two cylindrical housing bores, each housing bore having an axis disposed parallel to the other axis and the first and second axes separated by a distance "a";

at least a first screw shaft and a second screw shaft being disposed in the first and second housing bores; the first and second screw shaft being provided with a first and second screw respectively, each screw including at least one element; the first and second screw each having an extruder diameter D and a screw root diameter d; the first and second screw shaft each having a volumetric ratio of at least 1.4 wherein the volumetric ratio is defined by the extruder diameter D divided by the screw root diameter d.

a first intake element coupled to the first shaft and including a first flight, a second intake element coupled to the second shaft adjacent the first intake element and including a second flight, wherein the first flight and the second flight are adapted to co-operatively

create a partial vacuum that acts as appositive displacement pump to convey material when the first intake element and the second intake element are rotated in the same direction;

at least two inlet hoppers being provided in the vicinity of the housing bores and opening into said housing bore with at least one of the inlet hopper having a side inlet into the housing bore;

the method comprising:

feeding material to be processed through the at least two inlet hoppers into the housing bores;

conveying the material through the extruder length from the inlet hoppers to the extruder outlet;

driving each of said first and second screw shafts at a speed of at least 1000rpm and at a torque density of at least 8.5 Nm/cm^3; the torque density defined by the shaft torque at each first and second shaft divided by the third power of the distance 'a' of the first and second axis.

5. A method as claimed in claim 4 wherein the first flight and the second flight define an undercut.

6. A method as claimed in claim 5 wherein the undercut is less than 85°.

7. A method as claimed in claim 1or 4 wherein the extruder is operated at a torque density of at least 17 Nm/cm^3.

8. A method of extruder operation substantially as herein described with reference to and as illustrated by the accompanying drawings.

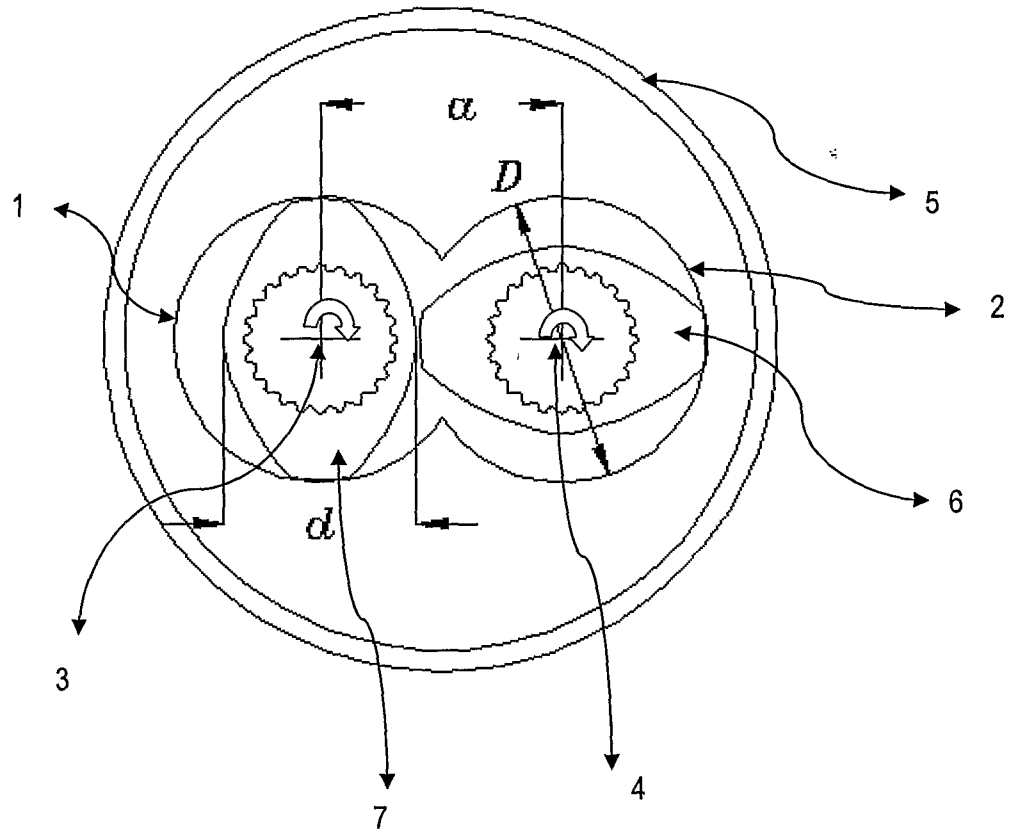


Figure 1

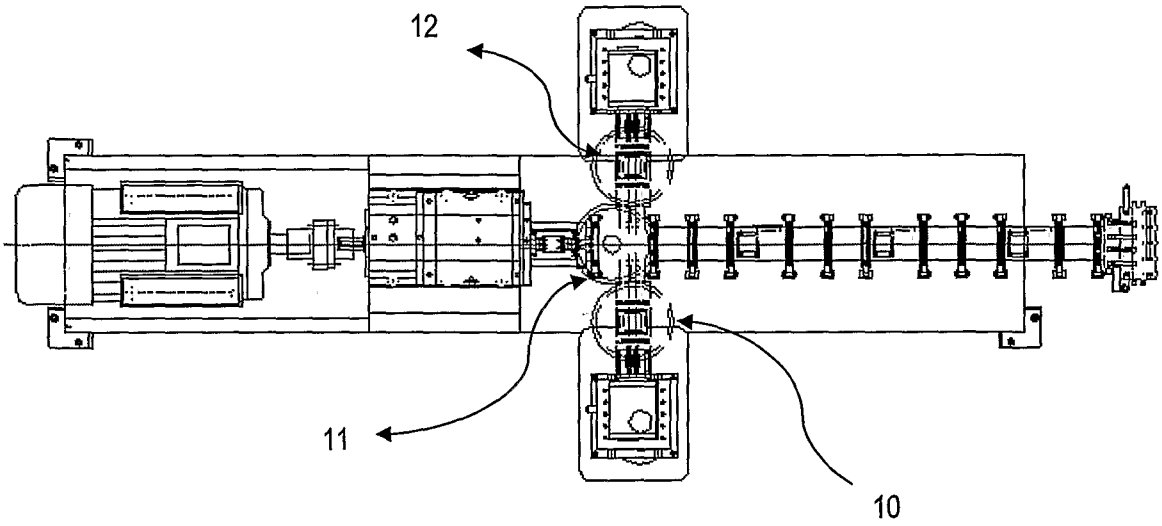


Figure 2

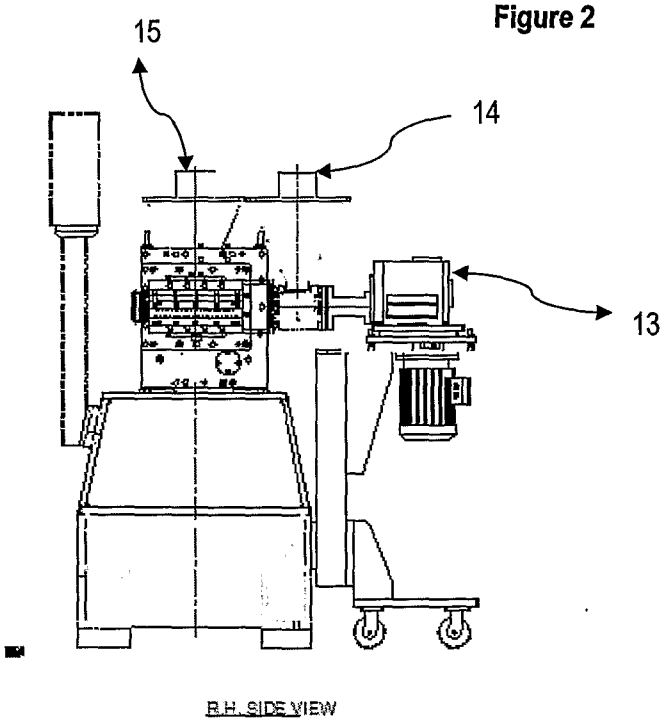


Figure 3

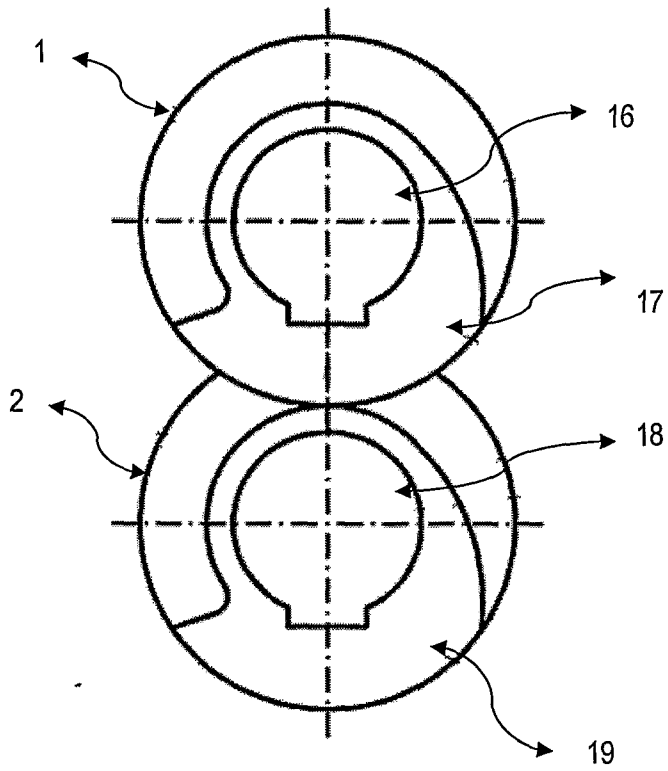


Figure 4

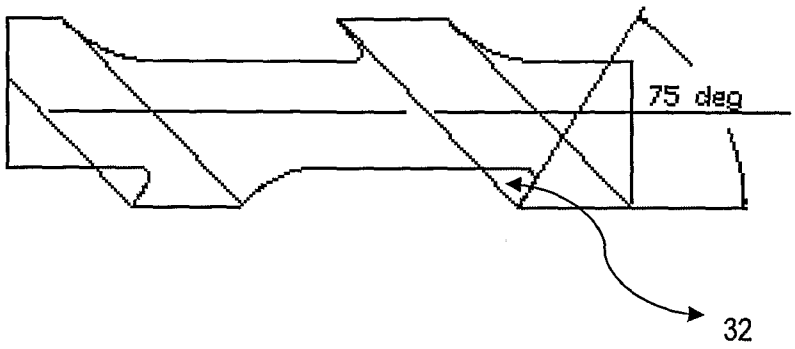


Figure 5

D/d	Extruder Diameter (D)	Screw root Diameter (d)	Flight depth (f)	Shaft diameter	Volumetric Capacity @ 1000 RPM (m^3/h)	Available Torque Nm	Specific Torque (Nm/cm^3)	Power kW @ 1000 RPM
1.27	23.5	18.5	2.5	14.5	0.321	85	9	18
1.4	24.4	17.4	3.5	13.4	0.418	80	8.5	17
1.49	25	16.8	4.1	12.8	0.495	80	8.5	17
1.55	25.6	16.5	4.55	12.5	0.546	103	11.0	22
1.71	26.5	15.5	5.5	11.5	0.6795	103	11.0	22
1.89	27.4	14.5	6.45	10.5	0.819	85	9.0	18

Table 1: Table showing Volumetric Capacity and Power for 21.1mm center distance Extruder

Feed limit (Typical) Specific gravity 0.5	Torque limit (Typical) Sp. E = 0.18 kWh/kg)	Volume (l)	Residence Time (s) at 50% fill at 100 kg/h (Melt density = 1 g/cc)	Residence time (s) at typical feed limit	Residence time (s) at typical torque limit	Shear Rate Factor (D/f)	D/d
160.5	98	0.21	3.85	2.4	3.92	9.40	1.27
209	93	0.28	5.02	2.4	5.40	6.97	1.4
247.5	93	0.33	5.94	2.4	6.39	6.10	1.49
273	120	0.36	6.55	2.4	5.45	5.63	1.55
339.75	120	0.45	8.15	2.4	6.78	4.82	1.71
409.5	98	0.55	9.83	2.4	9.99	4.25	1.89

Table 2: Table showing Residence Time and Shear Factor

Shaft Torque Capacity (H13 hardened) Nm	Shaft Specific Torque (Nm/cm^3)	Power kW @ 1000 RPM	Feed limit kg/h (1 specific gravity)	Feed limit Kg/h (0.1 specific gravity)	Torque limit (0.25 kWh/kg)	Torque limit (0.1 kWh/kg)	D/d
229	24	48	321	32.1	192	479	1.27
180	19	38	418	41.8	151	378	1.4
157	17	33	495	49.5	132	329	1.49
146	16	31	546	54.6	123	307	1.55
114	12	24	679.5	67.95	96	239	1.71
87	9	18	819	81.9	73	182	1.89

Table 3: Table showing best combination of Torque and Feed limits with D/d = 1.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2008/000861

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

B29C 47/38 (2006.01) ***B29B 7/46*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPI, EPODOC; IPC Marks - B29C47/38 - 47/50, B29B7/46 - 7/48; Key Words - volume+, torq+, vacuum+;

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2359271 A (KRUPP WERNER & PFLEIDERER GMBH) 22 August 2001 See Page 1 line 26 – Page 2 line 13	1 – 3
X	US 6042260 A (HEIDEMEYER ET AL.) 28 March 2000 See Abstract	1 – 3
X	US 2004/0262807 A1 (STURM ET AL.) 30 December 2004 See Paragraphs [0018] – [0020]	1 – 3
A	US 4040607 A (ULLRICH) 9 August 1977 See Abstract	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 June 2009	19 JUN 2009
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **PRAVEEN JAIN** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6222 3653

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2008/000861

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5621024 A (EBERHARDT ET AL.) 15 April 1997 See Abstract	
A	EP 1136228 B1 (F. LLI MARIS S.P.A.) 26 September 2001 See Abstract	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2008/000861

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: **8**
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

The claim does not comply with Rule 6.2(a) because they rely on references to the description and/or drawings

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/IN2008/000861

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
GB	2359271	CH	694795	DE	20015290U	FR	2804365
		IT	TO20010013U				
US	6042260	AU	68718/96	BR	9610732	CA	2231353
		CN	1198124	DE	19536289	EP	0852533
		NO	981327	WO	9712746		
US	2004262807	BR	0212427	CN	1555307	DE	10144748
		EP	1425151	MX	PA04002375	US	2005248052
		WO	03022550				
US	4040607	BE	833819	CA	1055217	CH	602171
		DE	2446436	FR	2285987	GB	1521142
		JP	51060253	NL	7511380		
US	5621024	CA	2160953	DE	4437586	EP	0708124
		JP	8188634	MX	9504410		
EP	1136228	IT	TO20000278	US	6447156	US	2001031289

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX