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Micronisation technology review for stabilised red meat co - products

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1 Abstract

Previous work has shown that it is possible to convert a range of red meat co-products (including blood, lungs, hide, bone and trim) to a powder in a single pass of a particular non commercial pilot mill (Mill-27) enabling significant commercial benefits from bioactive recovery to added value food products. This project has reviewed alternative commercial mills globally and has identified 54 processes which have the potential to stabilise co-products in a similar manner through size reduction and drying. By evaluation, rating and comparison with Mill-27's key aspects a group of 5 mills have been recommended as the best options for trial evaluation, preferably with an MLA stakeholder. This project has identified that technologies exist today which should fulfil the requirements for stabilising co-products and that minimal development is required to make this as a reality.

2 Executive summary

While utilisation is a key factor for the Australian red meat industry, there is a clear opportunity to add value to the 62% of the slaughtered animal going into co-products. One way to assist this is to stabilise these materials maintaining their functional aspects for use in food or further co-product processing. A previous project A.MPT.0027 (powdered meat technology feasibility trials) demonstrated that it is possible to convert a range of carcass components into a dry powder in a single pass through a particular mill. This mill was a prototype and required significant development, which MLA was unable to negotiate a co-operative commercial arrangement with the owners to do.

This project sought to identify potential milling technologies that would be appropriate to the production of stabilised dry or semi-dry powders, from raw materials which might include blood, bone, skin, trimmings, internal organs, glands and waste streams. The potential of this sort of process for the red meat industry lies in the very efficient size reduction and heat transfer rates achievable, which means co-products may be stabilised to low moisture levels without severe long temperature exposure.

Identification and characterisation of the key milling aspects for Mill-27 have been proposed to assist in the review of potential milling technologies. The review identified that Mill-27 is distinctive in that it forms a differential pressure chamber which cycles up to 60,000 times a minute.

Existing milling operations have been identified and reviewed with a summary list of 54 mills being rated and selected as having potential to stabilise red meat co-products through meeting requirements based on material, rate and product specification. This list has been reduced through selecting those rating in the top 25%, resulting in 13 mills which have been further rated and ordered against Mill-27's key aspects.

It has been concluded that any of the 13 mills would provide a viable solution to stabilising red meat co-products, requiring less development than Mill-27. It is proposed that the top 5 mills be considered as this will ensure a more effective result.

It is recommended that a project be undertaken to evaluate, trial and select the best of these 5 mills with a range of co-products, including a cost benefits analysis and that this be done in association with an MLA stakeholder if possible. It is also recommended, with a lower priority to the above, that the concept of cavitation as a mechanism for aiding size reduction and drying design, be proven through adapting commercially available equipment identified in this review.

In the short term these developments will enable the characterisation and cost benefits estimation of potential markets for these stabilised co-products, while enabling the necessary information for stakeholders to plan for capital investments to realise these benefits - from use in restructured meat products to dewatering alternative fuels for boilers in processing operations.

Over a five year time frame it is expected that these processes would provide returns to stakeholders by ensuring that the value of co-products is maximised by maintaining functionality of the materials through stabilisation. This project has identified that technologies exist today which should fulfill the requirements for stabilising co-products and that minimal development is required to make this as a reality.

Contents

3 Background

While utilisation is a key factor for the Australian red meat industry, there is a clear opportunity to add value to the 62% of the slaughtered animal going into co-products. One way to assist this is to stabilise these materials maintaining their functional aspects for use in food or further co-product processing.

Project A.MPT.0027 (powdered meat technology feasibility trials) demonstrated that it is possible to convert a range of carcass components into a dry powder in a single pass through a particular mill. Such powders represent a novel class of red meat based ingredients for food manufacture and MLA is keen to explore the commercial feasibility of such ingredients and products. The original equipment was a prototype and no commercial version exists. MLA attempted to negotiate with the owners of the technology to help develop and assess a food grade version for product and process development studies, but an impasse on IP ownership lead to a failure of these negotiations.

This project is to review and identify alternative commercially available milling and comminuting equipment which could be effectively applied to stabilise red meat co-products

4 Project objectives

This project will identify potential milling technologies appropriate to the production of stabilised dry or semi-dry powders for use in food and further co-product processing. Raw materials which might be converted to such powders include blood, bone, skin, trimmings, internal organs, glands and waste streams.

The potential of this sort of process for the red meat industry lies in the very efficient size reduction and heat transfer rates achievable, which means co-products may be stabilised to low moisture levels without severe long temperature exposure.

5 Methodology

Milling or comminuting is the breaking down of solids through applying mechanical forces. While there are many milling operations they all make use of one or more of 3 ways of applying force : compressive (roller crushers), impact (hammer milling) and shear (attrition milling). This is made more complex when size control is added in the form of classifiers (with screens, weirs, gaps or density separators). To ensure that this review highlights those processes that will provide the best potential milling operations, the following methodology will be applied.

1. Identification and characterisation of the key milling aspects which made the A.MPT.0027 milling operation (Mill-27) functional for red meat co-products

2. Identification and review of existing milling operations against key milling aspects for red meat co-products

3. Review of best potential operations with Mill-27 and through direct discussions with manufacturers.

4. Prepare report and publish findings with recommendations on how best to proceed.

6 Results and discussion

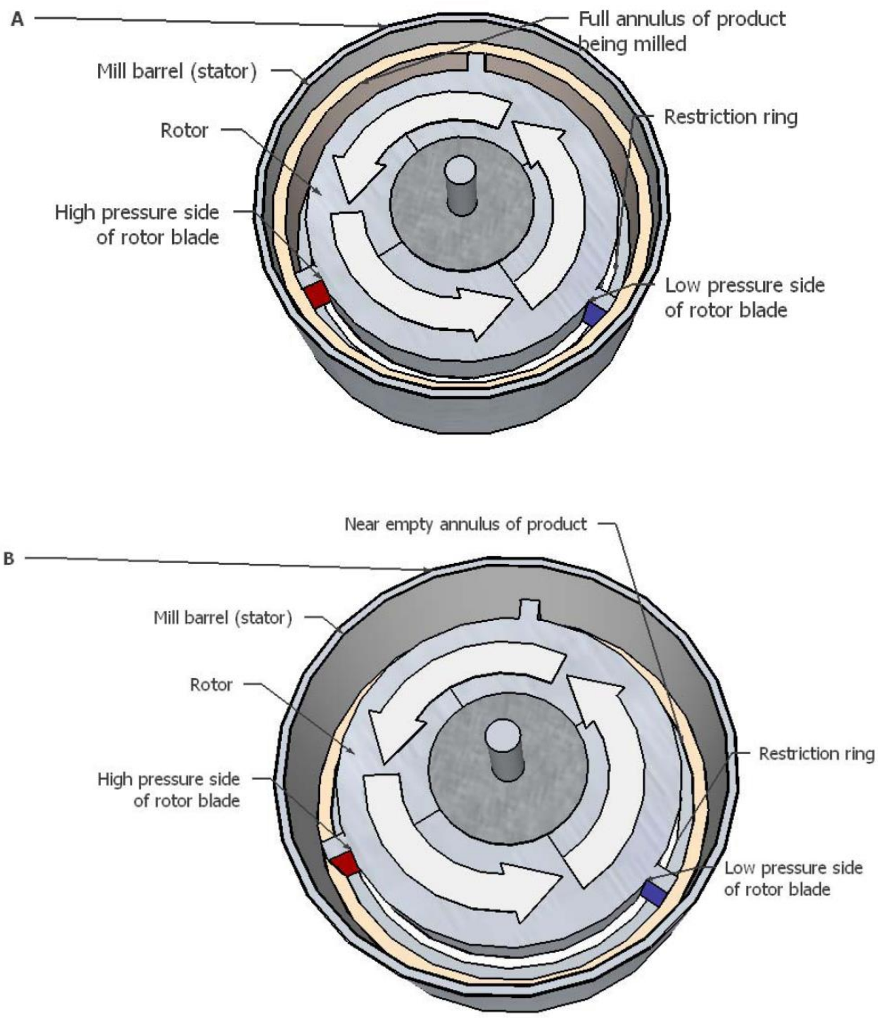
6.1 Identification and characterisation of the key milling aspects for Mill-27

The functionality of Mill-27 is primarily focused on its ability to stabilise through water activity (a_w), red meat co-products while maintaining their bioactive/functional potential. The trial process was presented as a mechanically driven version of a fluid energy or jet mill, where material is accelerated within a circular or oval chamber and continually redirected to collide with itself, size reducing through impact and attrition. While this is generally the case, it appears that other forces may also be employed which enable this process to utilise rapid energy transfer and generate much more drying than is indicated using jet milling. Identification and discussion of the proposed *key aspects* for Mill-27 follows with respect to milling/drying

6.1.1 Mill outlet control

As noted in A.MPT.0027 report, product retention within Mill-27 appeared to be less than 1 second and yet the theoretical retention time should be around 4 minutes based on operating volume (see Appendix 1). This can only mean that the Mill-27 was never achieving maximum operating volume (see Figure 1) until the outlets blocked up.

Figure 1 Schematic of operating volume for Mill-27, A – maximum. B - proposed actual.



From figure 1, this further indicates that the mill's capacity is potentially far higher than initially perceived and that control over the outlet rate (restriction ring) from this type of mill is very important.

Milling of fatty, wet and sticky materials is generally not compatible with any static mesh screening outlets when the apertures are small, as they tend to blind the screens and overload the mills[1]. Gaps, while less defining in grind size are more applicable, however they do need to be adjustable for different materials. Some classifiers (air or rotor driven) can function effectively as adjustable outlet control for these materials (based on manufacturer's recommendations).

Aspect: *Adjustable outlet gap/classifier, no static mill screen*

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[1] Retsch GmbH (2008). The Art of Milling - An expert guide, Retsch GmbH, Haan.

6.1.2 Rotor tip speed and frequency

Particle to particle impact mills depend heavily on the energy of the impacting particles and this is directly related to their velocity (i.e. Energy = ½ *mass*(velocity)^2). In Mill-27 both the number (frequency) and the speed of the rotor tips influence this, in air jet mills this energy is achieved through use of compressed air (or super heated steam) injection at multiple points. Mill-27 ran with a tip speed between 200 and 260 m/s, which is usually only found in laboratory type equipment.

As a significant amount of the energy is converted to heat in the particle collisions, which is lost through air exiting the mill, a high frequency effectively enables recharging within each cycle. Obviously there is a limit to the frequency (number of rotor blades) be it physical space or load exerted on the drive system. The Mill-27 had a frequency of up to 60,000 cycles per minute ensuring a good energy recharge.

Aspect: *Very high speed (200 m/s) and frequency to maximise energy input*.

6.1.3 Gap between rotor blade tip and barrel wall

This gap impacts retention time directly through changing the operating volume (i.e. making the annulus of product thinner with a smaller gap). The thinner the gap the more shear force will be exerted on the product and the greater the energy provided to the product but for less time, this requires finding the balance where the maximum energy can be transferred to the product overall. With wet, fatty or sticky materials the gap is usually larger, which was needed for red meat co-products in Mill-27. This can be balanced with the mill outlet rate

6.1.4 Air flow rate

With jet mills, air flow rate tends not to be limiting as it is the source of energy. With Mill-27 the source of energy is primarily the rotor, air flow is provided by both a cyclone and an additional side channel blower (a means of boosting air flow) which ensures the moisture removed can be both evacuated instantly and not condense out before exhausting from the cyclone or bag house. The minimum air flow required, to carry the water removed, when running lung at 12 kg/hr (as trialled) is 87 m^3/hr of dry air - this is at saturation (see Appendix 2).

A full scale production process is likely to need more than 7.25 m3/hr of dry air for each kilogram of product feed (see Appendix 2), hence any alternative milling process will also need to handle the same or more to be functional for red meat co-products.

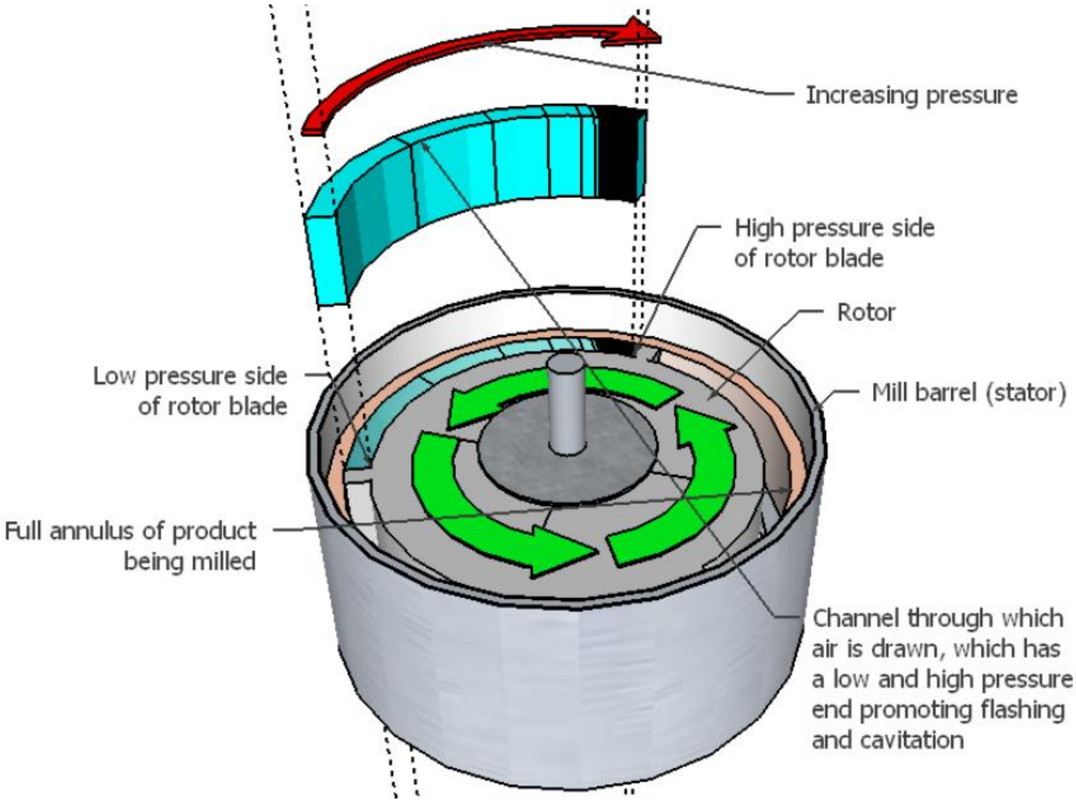
Aspect: *Very high air flow, at least 7.25 m3/hr of dry air for each kilogram of product feed*

6.1.5 Cavitation and moisture flashing

The drying rates observed in the Mill-27 (with milling retention time of less than 1 second) indicate that there may be other physical processes than convective and diffusion driven moisture removal.

It was proposed in project A.MPT.0027 that this may be due to the pressure differential that would exist across the face of the rotor blade, the front experiencing compressive forces with the blade moving at nearly 1000 km/hr (see Appendix 1). Similarly the back of the blade would experience a significant drop in pressure with resulting eddies being formed, consequently within the mill there is formed an air chamber of sorts where the product experiences an oscillation from low to high pressure (see Figure 2).

Figure 2 Schematic of proposed differential pressure chamber for flashing and cavitation



So from Figure 2, the face of the product annulus between the two rotor blades experiences a very localised pressure oscillation up to a 1000 times a second (see Appendix 2). This is a lot less likely to occur if there was not this 'chamber like channel' bounded by the rotor blades, the rotor and the product annulus. This is believed to be a very key aspect to this process.

It is proposed that at the low pressure end of this chamber significant flashing occurs due to the pressure drop experienced by the product as the rotor blade passes, remembering that a vacuum is being pulled on the system to pull the large volumes of air through. As the next rotor blade approaches those bubbles formed that are trapped locally within the product annulus (i.e. unable to flash at the product annulus surface of 'the chamber') could experience cavitation (i.e. they implode). It has been shown that the release of the energy trapped within hydrodynamic cavitation bubbles can result in micro localised temperatures over 5000 K and a pressure of about 1000 atm[2]. This energy combined with that being introduced through the compression forces of the on-coming

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[2] Pinjari, D. V. and A. B. Pandit (2010). "Cavitation milling of natural cellulose to nanofibrils." Ultrasonics Sonochemistry **17**(5): 845-852.

rotor blade likely lead to the high flashing as the rotor blade passes generating eddies and entraining air into the product as the next cycle starts and continues.

It is not known if cavitation is occurring within Mill-27, but it is believed that it could be verified by applying the measurement technique using aqueous potassium iodide which breaks down in the presence of cavitation only, this has been used to measure the extent of cavitation[3].

We know that the side channel blower can pull a vacuum down to 29.5 kPa[4] (which means water would flash at around 69 ºC), however with high air flows this will not be achieved (only when the in-feed is partially blocked). While the rotor blade will certainly have a high pressure and low pressure side, pressure measurement at these speeds would be challenging, but would enable calculation of the cavitation number Cv [5] [6](see Equation 1). This equation is a measure of collapsing forces over generating forces

Cavitation Number $$\mathrm{Cv} = \frac{\mathrm{P}_2 - P_v}{\frac{1}{2}\rho V^2} \qquad (1)$$

Where P_2 is the local recovered pressure, P_v is the vapour pressure, ρ is the fluid density and V is the velocity through the constriction. The geometry and velocity of oscillations can have a significant effect on the value of when cavitation will occur[7], for orifice plate systems this tends to be when Cv ≤ 1.

[3] Shirgaonkar, I. Z., R. R. Lothe, et al. (1998). "Comments on the Mechanism of Microbial Cell Disruption in High-Pressure and High-Speed Devices." Biotechnology Progress **14**(4): 657-660.

[4] Anon. "Industrial Blowers - Performance Graphs, ESAM Air Technology ". Retrieved 24 April 2012, from http://www.sidechannelblowers.com.au/blowers/graph#vacuum.

[5] Pinjari, D. V. and A. B. Pandit (2010). "Cavitation milling of natural cellulose to nanofibrils." Ultrasonics Sonochemistry **17**(5): 845-852.

[6] Jyoti, K. K. and A. B. Pandit (2001). "Water disinfection by acoustic and hydrodynamic cavitation." Biochemical Engineering Journal **7**(3): 201-212.

[7] Moholkar, V. S. and A. B. Pandit (2001). "Modeling of hydrodynamic cavitation reactors: a unified approach." Chemical Engineering Science **56**(21–22): 6295-6302.

Hence in summary, it is difficult to confirm cavitation in this mill other than by direct measurement or modelling.

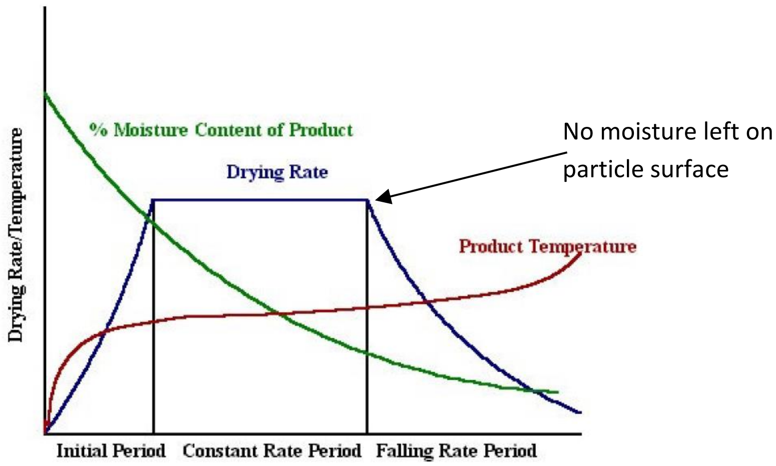
For Mill-27 to achieve the size reduction and drying with such short retention times (running near empty) in less than 1 second, indicates that the system must be hyper-dynamic as significant extraction of moisture from within a 10 cm annulus of product with the addition of no external heat in this time frame otherwise seems questionable.

Aspect: *Ability to form a differential pressure chamber to drive flashing*.

6.1.6 Mill temperature

The energy delivered to the product material by what ever means, will result in some heat generation. While the product is still moist, most of this will be lost as moisture flashing. As drying of a product/particle proceeds to the falling rate period see Figure 3, the material starts to heat up as energy applied through milling or added heat has no moisture at the surface to flash. The drying rate at this stage depends on moisture mass transfer from within the particle to reach the surface. As we reduce the size of the particles this period has less impact, noting that every product has different drying curves for different process conditions and from the moment a particle enters a drying process these conditions are changing. However as the material dries a means of maintaining the temperature is required especially with products like bone and hide which did require cooling.

Figure 3 Product Drying Curve and Drying Rate Periods (adapted from[8 9])



[8] Berk, Z. (2009). Chapter 22 - Dehydration. Food Process Engineering and Technology. San Diego, Academic Press: 459-510.

[9] Devki Energy Consultancy Pvt. Ltd. (2006). Best Practice Manual - Dryers. Energy Manager Training, Ministry of Power (India).

This was effectively achieved with jacket cooling on Mill-27 and was maintained below 55 ºC. This was the maximum overall temperature of the product material, it is recognised that at a micro scale localised temperatures can be a lot higher. The temperature is more important when retention times are higher, but to avoid any significant protein denaturation mill temperatures below 60 ºC were targeted. The ability of Mill-27 to achieve the drying rates while maintaining product temperatures in this region is a key aspect

Aspect: *Mill cooling to maintain product temperature below 60 ºC*.

6.1.7 Mill operation

Mill-27 was trialled with a range of co-products being, Lungs, Bones, Hide, Trim and Blood, all except Blood were able to be run in a single arrangement by changing just mill speed. While each performed differently, the same arrangement gave the best results for each. This flexibility is a very key aspect and would result in effective mill operation.

Aspect: *Flexible material milling operation*.

Mill-27 had several negative operational aspects which were highlighted during the trials and are noted here as aspects to consider with alternative milling equipment.

1. Ability to have rate controlled in-feed (volumetric or mass)
2. Hygienic design with simple and quick access for cleaning
3. Fat friendly milled product recovery system (preventing fat solidification)

The above aspects have been used to review possible alternative milling equipment in section 4.3

6.2 Identification and review of existing milling operations against key milling aspects for red meat co-products

6.2.1 Milling categories

There are many milling equipment designs utilized for size reduction, broadly these can be characterized as presented in Table 1:

Table 1 Mill Category and Type by Size Reduction adapted from[10] [11]

Category	Principal type	Type	Size reduction
a. Primary and secondary crushers	1. Gyratory crushers 2. Jaw crushers 3. Roll crushers	Ring mills	Prim. → 200mm Sec. 200mm → 5mm
b. Intermediate and fine grinders	1. Impact mills 2. Attrition mills 3. Tumbling mills (media mills, wet or dry) 4. Rolling-compression mills	a. Hammer mills b. Centrifugal pin mill a. Ball and pebble mills b. Rod mills c. Tube mills; compartment mills a. Ring roll mills b. Bowl mills	Int. 5mm → 0.42mm Fine 5mm → 0.075mm
c. Ultrafine grinders	1. Fluid-energy mills 2. Agitated mills 3. Impact mills with internal classification	a. Mill-27 b. Jet mills Nutating mills	5mm → 1 to 10 µm
d. Cutting machines	1. Knife cutters, dicers, slitters		→ 2 to 10 mm

These are very broad classifications as application of each further depends on both the material to be processed (hardness and friability) and the desired outcome required (including rate and finished product specification). This has resulted in a very diverse range of grinding equipment and a large number of niche applications from mining diamonds to pharmaceutical preparation for absorption control resulting in thousands of available milling options.

For this application of stabilizing red meat co-products the following requirements can be identified to enable narrowing down the mill options for review.

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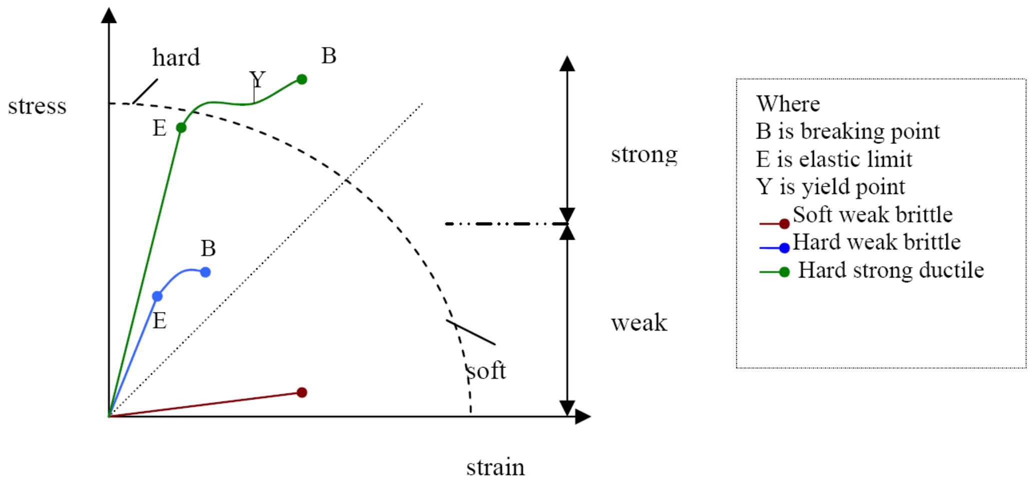
[10] (2011). Size Reduction. Unit Operations of Particulate Solids, CRC Press: 179-206.

[11] Sunil, K. (2012). Size Reduction. Particle Technology and Applications, CRC Press: 125-144.

6.2.2 Material type:

Materials can be characterised on a stress strain plot as to whether they are weak or strong, hard or soft and brittle or ductile see figure 4. For example the blue line may be egg shell being hard weak and brittle. Brittle material size-reduce well with impact forces and are considered friable, like bone.

Figure 4 Material characterisation by stress strain plot



Materials with elastic or viscoelastic properties (like meat or hide) tend to absorb a significant amount of compression or impact energy through deforming and require shearing forces to size reduce more efficiently[12 13]. Except for blood all of the co-product materials may be considered fibrous solids having a Mohs ratings between 0 and 5 (Note: Mohs scale is 0 to 10 with Talc being 0 and diamond being 10 and is non linear, materials being ranked based on their ability to scratch others on the scale). While apatite ($Ca_5(PO_4)_3(OH^-,Cl^-,F^-$) of which bone is the hydroxy version) is rated 5 on the scale, wet bone is likely to be less, this puts these materials at the soft end of the scale.

Consequently some impact but mainly attrition/shear or cutting[14], are more likely to be successful. Cutting while significantly improved over the recent years, is still limited in size reductions to around 0.2 mm (200 µm), which is likely to delay drying due to the impact of the *falling rate period* (where mass diffusion limits the drying rate).

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[12] George D. Saravacos and A. E. Kostaropoulos (2002). Handbook of Food Processing Equipment, Kluwer Academic/Plenum, New York.

[13] Retsch GmbH (2008). The Art of Milling - An expert guide, Retsch GmbH, Haan.

[14] Ibid.

Requirement - *Most materials being soft and fibrous will size reduce/dry more efficiently using attrition/shear operations primarily, with some impact.*

6.2.3 Rate and final specification

The rate will be dictated by the size of the operation, this is very 'abattoir' related, however as an estimate the following is proposed. While there are both large and small abattoir processors, the 19 largest beef and veal processing companies have been estimated to have processed around 1.5 million tonnes in 2003[15] this would give an approximate processing rate required of each, for hides of 1 to 1.5 T/hr (hides being ~ 7% of carcass weight[16]).

If most co-products were to be processed, then processing rates up to 5 T/hr may be required. For this review, a rate of 1 T/hr will be adopted such that it could be economically feasible while still being 'technologically doable'.

The final specification of product is, that it is 'stabilised'. Hence to achieve this with Mill-27 the particle size range was 1 to 200 µm for hide with the majority being at the lower end, for flash drying this is a key aspect. From Table 1 this range can be achieved by most fine and ultrafine grinders only.

The drying requirement dictates that the mill must operate under air assistance to carry the moisture away, while 'a must' this aspect may be adapted as it has with a number of mill types, especially if a mill has the other necessary aspects.

The ability to handle fatty, wet and sticky products is necessary (all co-products fit in this description) and most milling systems with 'fixed screens' for classifying do not[17 18]. Some however have potential to operate without their screens or have rotating classifiers, these have been considered.

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[15] (JUNE 2006). A Review of the Structure and dynamics of the Australian Beef Cattle Industry. D.A.F.F., Ausvet Animal Health Services.

[16] Stephen. De Martin (2003). The Fifth Quarter, Meat and Livestock Australia. **No 11**.

[17] Retsch GmbH (2008). The Art of Milling - An expert guide, Retsch GmbH, Haan.

[18] (2011). Size Reduction. Unit Operations of Particulate Solids, CRC Press**:** 179-206.

Media mills which use balls, rods or tubes accelerated by gravity centrifugation or agitators at first appear an option, as when the media is small and the motion fast, high levels of attrition/shear can be achieved (like Mill-27 with media processing blood)[19]. However while the small media give a fine grind size, with fibrous products, the high elasticity results in longer milling times (hours) as the media's energy is often lower than the 'Youngs modulus' needed for fracturing the particles. This will likely defeat the purpose for stabilising the products in the first place, only the newest of these mills have been considered.

Mills which use very high pressure air (some air jet mills) without an extraction system lowering the pressure at the out-feed have been discarded, as the increased pressure significantly drops the moisture carrying capacity of the air as shown in Appendix 4.

In summary, the following rate and specifications are requirements:

Mills need to fit the fine or ultrafine type to achieve a 1 to 200µm particle size for effective flash drying.

Mills need to be adaptable to process with at least 7,250 m^3/hr of air to carry the moisture removed from 1T/hr of feed material.

Mills will need to operate without static screens to handle 'fatty', 'wet' and sticky materials.

A summary list of the mills identified as having potential to stabilise red meat co-products based on these requirements is given in Table 2 and a schematic summary of their operation included in Appendix 3.

The key aspects identified in Table 2, have been selected from the requirements identified above and those identified for Mill-27. The mills highlighted are those best meeting the 'material', 'rate' and 'final specification' requirements only.

There are a number of figures that have been unable to be obtained, these have been recorded as a '**?**'**.** A number of manufacturers correctly point out that rate is very material dependant, however rates combined with airflow, enable a broad understanding of energy conversion. Where rate has been provided for a test machine and scale-up factors are available, these have been used.

Each mill has been assessed and scored first for 'out-feed' grind size (min) and rate, then ability to handle fibrous, 'fatty-wet-sticky' material and airflow – the top 13 (as highlighted) were selected as the only mills scoring 6/10 or higher (the top 25%). The ratings have been included in Table3

It is possible that any of the mills in table 2 could be adapted to effectively size reduce red meat co-products. Those selected, are the most likely to be adapted to size reduce and dry red meat co-products effectively at the required rate.

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[19] Dahm, C. (2010). Powdered meat technology feasibility trials. Final Report, Meat & Livestock Australia Limited.

It should be noted that while machine rate has been considered, an efficiency assessment of energy conversion has not. The objective has been to find how to achieve the *functional* stabilisation, by water activity, of red meat co-products at around 1 T/hr. Some of the equipment considered has motor ratings as high as 700 kW (Hosokawa Alpine LGM), but most are 250 – 500 kW. However to remove 750 kg/hr of moisture (processing lung at 1T/hr) will require around 500kW for the latent heat of evaporation alone without any sensible heat input or efficiencies so the power requirements are a relative match.

These mills are expected to not only provide a stabilised functional material of significant added value but to potentially improve the energy efficiency of the abattoir processes also. The conventional rendering process in Ireland, consumes both; electrical - 270 megajoules (MJ), and thermal - 2790 MJ of energy per tonne[20], so processing 1 T/hr would utilise 850 kW of processing power for size reduction and drying. It should be noted that the thermal process does cater for Specific Risk Material (SRM) processing requirements, whereas these mills may be constrained by what can be processed, as they are in effect low temperature processes.

[20] (2009). Sustainable Practices in Irish Beef Processing, Dept of Jobs Enterprise & Innovation, Enterprise Ireland.

Table 2 Summary list of Manufacturers Mill's 'key aspects' with the potential to stabilise red meat co-products

Mill No.	Manufacturer	Mill type (1^0 /2^0 method)	Name	Infeed size mm (max)	Outfeed size µm (min)	Tip velocity (m/s)	Air flow m^3/hr (Adaptable yes/No)	Food Grade options	Drying options	Pot. to modify for flash drying (Yes/No)	Rates max.T/hr (evap T/hr)	Added Cooling (Yes/No)	Flexible (Yes/No)	Trial facilities available (Yes/No)	Added Size control (type)	Points of Interest/issue
1	Bauermeister	Stator/Rotor (Impact/shear)	Gap Mill GM-D	5	25	?	6,800 (Yes)	Yes	No	Yes	9	Yes	Yes	Yes	Yes (Gap)	Tangential discharge an option
2	Bauermeister	Stator/Rotor (Impact/shear)	Gap Mill GM-P	5	25	123	—	Yes	No	Maybe	—	Yes	Yes	Yes	Yes (Gap)	Designed for paste Turbo mill style
3	Alligrator (Aus) Pty Ltd	Hammer (impact)	Alligrator	25	~ 100	100	1600 (Yes)	Yes	No	?	3	Yes	Yes	Yes	No	Has processed bone no good with nonfriable
4	Mahltechnik Gorgens GmbH	Stator/Rotor (shear/impact)	Turborotor	25	5	90 - 150	50,000	Yes	Yes	Yes	(4 water)	?	Yes	Yes	Yes (Ext classifier)	Robust
5	Ultra Febtech Pvt Ltd	Stator/Rotor (shear/impact)	Ultrafine Pulverizer	?	2.5	?	? (Yes)	Yes	Yes	Yes	?	?	Yes	Yes	No	Limited information, no response
6	Buhler AG	Hammer? (impact/shear)	Unimill	25	?	?	?	Yes	No	?	1	?	Yes	Yes	No	Rugged, but may not be fine enough
7	Nisshin Engineering Inc.	Stator/Rotor (shear/impact)	Super Rotor Mill	5	5	160	3600 (Yes)	Yes	Yes	Yes	0.3	Yes	?	?	No	Very similar to Mill 27 low rate - may be increased
8	Nisshin Engineering Inc.	Jet Mill (shear/impact)	Super Jet Mill SJ-10K	2	1	—	1080 (?)	Yes	No	(?)	0.3		?	?	Yes (Int. classifier)	Little information, but clever classifier
9	Sturtevant Inc.	Pin Mill (impact only)	Simpactor			230	? (Yes)	yes	No	Yes	40 +	No	Yes/No	Yes	No	Replacing pins with beaters req. for fibrous
10	Sturtevant Inc.	Jet Mill (shear/impact)	Micronizer	1	0.5	—	5600 (?)	Yes	No	Yes	4	No	Yes	Yes	No	Jet mills expensive to run, but good for drying
11	Sturtevant Inc.	Stator/Rotor (impact/classifier)	Powderizer	5	10	?	25,500	Yes	Yes	Yes	7	No	Yes?	Yes	Yes (classifier)	Small rotor/beater - Fat?
12	Stedman	Stator/Rotor impact/minor shear	VSlam vertical shaft impactors	250	44	63	?	No	No	Yes	500	No	Yes	Yes	No	Robust needs a lot of modifying
13	Stedman	Stator/Rotor impact/shear	Micro-max	?	?	?	16,300	Yes	Yes	Yes	?	Yes	Yes	Yes	No	Cooling - injection for nonfriable
14	RSG Inc.	Agitated media (shear/impact)	*ufg* Mill	3	1	—	?	Yes	?	No	low	?	No	Yes	Yes (Ext classifier)	Low rates
15	RSG Inc.	Hammer (impact/shear)	RSG Hammer Mill	0.5	45	?	Yes any	Yes	Yes	Yes	?	No	?	Yes	Yes (Ext classifier)	Friable only
16	IPEC	Stator/Rotor (shear/impact)	Rotormill	?	?	166	22,000	Yes	Yes	Yes	(3.5 water)	No	Yes	Yes	Yes (Ext classifier)	Handles fibre
17	CCE Technologies Inc.	Jet Mill (shear/impact)	Dense Phase Fluid Energy Mill DPM	0.5	1	—	2500	No	No	Maybe	low	?	No	Yes	Yes (Int. classifier)	will handle hide but slow

Table 2 cont.. 1

Mill No.	Manufacturer	Mill type (1^0 /2^0 method)	Name	Infeed size mm (max)	Outfeed size µm (min)	Tip velocity (m/s)	Air flow m^3/hr (Adaptable yes/No)	Food Grade options	Drying options	Pot. to modify for flash drying (Yes/No)	Rates max.T/hr (evap T/hr)	Added Cooling (Yes/No)	Flexible (Yes/No)	Trial facilities available (Yes/No)	Added Size control (type)	Points of Interest/issue
18	Vortec Products Company	Stator/Rotor impact/minor shear	M1 Impact Mill	3	5	250	Low	Yes	No	Maybe	0.25 & 4.5	No	Yes	Yes	Yes (Ext classifier)	Efficient impacting
19	Freund Turbo Corp. Patent -Turbo Kogyo Co Ltd	Stator/Rotor (shear/impact)	Turbo Mill S & M	3	45	130	4250	Yes	Yes	Yes	1.5	No	Yes	Yes	Yes (Ext classifier)	Very fine uses cryo.
20	Freund Turbo Corp.	Stator/Rotor (shear/impact)	Turbo Mill E, R & CR	?	25	146	4500	Yes	Yes	?	?	Yes (rotor)	Yes	Yes	Yes (Ext classifier)	Has partition discs for zones
21	Mill Powder tech Solutions	Stator/Rotor (shear/impact)	Turbo-Mill	3	44	104	4250	Yes	No	Yes	?	No	Yes	Yes	Yes (Ext classifier)	Vibrating classifier?
22	Alstom Power	Ring Mill (compression/shear)	Raymond Ultra Fine Mill	?	0.2	—	high?	No	No	Maybe	3.5	No	No	No	Yes (Int. classifier)	More suitable to hard Material
23	Air Products	Stator/Rotor (shear/impact)	PolarFit, Ultra fine grinding mill	?	10	84 - 115	10,000	Yes	No	Maybe	?	Yes (N_2)	Yes	Yes	Yes (Int. classifier)	Classifier static?
24	CMS Classifier Milling Systems Corp.	Stator/Rotor (Impact/shear)	Air Swept Classifier Mill	?	10	?	high?	Yes	No	Yes	high?	No	Yes	Yes	Yes (Int. classifier)	Airflow - need to know
25	British Rema Process Equipment Ltd	Stator/Rotor (Impact/shear)	Rema Rotary Classifier Mill	?	<300	119	9500	Yes	No	Maybe	2	No	Yes	Yes	Yes (Int. classifier)	Needs modifying
26	British Rema Process Equipment Ltd	Stator/Rotor (Impact/minor shear)	Rema Rotary Impact Mill		<300	?	10,200	Yes	No	Maybe	2	No	Yes	Yes	No	Must use no screen
27	Ningbo Grain Machinery	Abrasive disc (shear/impact)	MS60K Abrasive Disc Starch	3	80	—	0	Yes	No	No	1	Yes	No	No	?	Cheap but not for drying
28	Neue Herbold	Abrasive disc (shear/impact)	Pulverizer ZM 800	6	300	—	low	?	?	Maybe	1	yes	Maybe	No	gap	Needs flash drier
29	Shanghai Zhengyuan Powder R&D Co Ltd	Stator/Rotor (shear/impact)	Super Rotor Mill LHW 3000	?	5	84	high?	Yes	No	Yes	(2 water)	?	Yes	Yes	Yes (Ext classifier)	Impellers for in & out feed
30	Precision Products	Hammer rotor/stator (impact/shear)	Wizzon Mill	?	fine?	~95	medium?	Yes	No	Maybe	1.2	No	Yes	Yes	Yes (Int. classifier)	Internal fan for air flow
31	Precision Products	Rotor beater/stator (shear/impact)	Turbo Classifier Mill	6	30	91	5000	Yes	Yes	Yes	1	Yes	Yes	Yes	Yes (Gap plate)	Handles fibrous
32	Precision Products	Stator/Rotor (shear)	Whirlpul Micronizer Mill	3	90	?	?	Yes	?	Yes	0.3	Yes	Yes	Yes	Yes	Low rate
33	Poittemill Group	Stator/Rotor (shear/impact)	Attrimill	8	40	?	?	Yes	Yes	Yes	25	Yes (cryo.)	Yes	Yes	Yes (Ext classifier)	Limited info. but high rate

Table 2 cont.. 2

Mill No.	Manufacturer	Mill type (1^0 /2^0 method)	Name	Infeed size mm (max)	Outfeed size µm (min)	Tip velocity (m/s)	Air flow m^3/hr (Adaptable yes/No)	Food Grade options	Drying options	Pot. to modify for flash drying (Yes/No)	Rates max.T/hr (evap T/hr)	Added Cooling (Yes/No)	Flexible (Yes/No)	Trial facilities available (Yes/No)	Added Size control (type)	Points of Interest/issue
34	Poittemill Group	Jet Mill (shear/impact)	Fluidised Bed Air Jet Mill	0.25	3	—	high?	Yes	No	Maybe	3	Yes(cryo)	No	Yes	Yes (air classifier)	Limited info. but high rate
35	Poittemill Group	Stator/Rotor (Impact/shear)	Integrated Classifier Mill	8	10	?	?	Yes	Yes	Yes	50	No	Yes	Yes	Yes (Int. classifier)	Outfeed max 300µm (good)
36	Poittemill Group	Stator/Rotor (Impact/shear)	High Yield Pulverizer	30	80	?	?	Yes	Yes	Yes	50	Yes (cryo)	Yes	Yes	? (Ext classifier)	Handles fibre, prod to 600µm
37	Pallmann Maschinenfabrik GmbH & Co.	Stator/Rotor (Impact/shear)	TurboFiner PLM	15	finest?	140	?low	Yes	Yes	Yes	3.3	Yes	Yes	Yes	Yes (Ext classifier)	Uses temp not air vol to dry
38	Pallmann Maschinenfabrik GmbH & Co.	Stator/Rotor (Impact/shear)	Turbo Mill REF (or PP)	15	5	110	7,800 (2,580	Yes	Yes	Yes	?	Yes	Yes	Yes	Gap & rate	Can have added air flow, handles wide range of material
39	Pallmann Maschinenfabrik GmbH & Co.	Rotor beater/stator (shear/impact)	Contra Selector Mill PPSR	?	fine?	?	up to 18,000	Yes	Yes	Yes	?	Yes	Yes	Yes	Yes (Int screen)	Good air volumes, big motors does fat-wet-sticky
40	Netzsch-Condux Mahltechnik GmbH	Jet Mill (shear/impact)	Condux Fluidized bed Jet Mill CGS	1	2	—	11,660	Yes	No	Yes	2	No	Yes	Yes	Yes (Int. classifier)	Fatty products may not work
41	Ludowici	Agitated Mill (shear/impact)	Hicom Nutating Mill	25	5	50G	Maybe	No	No	Maybe	3	?	Maybe	Yes	Yes (Ext classifier)	Handles wet material, very high forces
42	KEK-Gardener Ltd	Stator/Rotor (shear/impact)	PPS Air Classifer Mill	5	5	110	up to 42,000	Yes	No	Maybe	2	Maybe	Yes	Yes	Yes (Int. classifier)	Flexible & very large air flow
43	Masuko Sangyo Co Ltd	Stator/Rotor (shear/impact/cutting)	Micro-Meister Mill 3M7-40	10	20	90	?	Yes	No	?	3	No	Yes	Yes	Yes (Int blade gaps)	Fast and small cutting & shearing
44	Masuko Sangyo Co Ltd	Stator/Rotor (shear/impact)	Ceren Miller ultra fine micronizer	10	5	?	?Yes	Yes	No	Yes	2.5	Yes	Yes	Yes	No	Uses patitions for zones - good
45	Hosokawa	Stator/Rotor (shear/impact)	Micron Flash Dryer	25	35	?	? High	Yes	Yes	Yes	?	No	Yes	Yes	Yes (Int. classifier)	Small footprint
46	Hosokawa Alpine	Stator/Rotor (shear/impact)	Alpine Long Gap Mill (LGM)	25	35	?	60,000	Yes	Yes	Yes	(6 water)	(cryo)	Yes	Yes	Yes (Int. classifier) in Mikro LGM only	Very good air, large hp
47	Hosokawa Micron	Stator/Rotor (Impact/shear)	Mikro Mak EC-CL	6	<100	?	450	Yes	No	Maybe	2.5	No	Yes	Yes	Yes (Int. classifier)	Designed for fibrous mat.
48	Hosokawa Alpine	Stator/Rotor (Impact/shear)	Contraplex Pin Mill CW	10	200	250 (relative)	23000	Yes	No	Maybe	3	(cryo)	Yes	Yes	No	High impact

Table 2 cont.. 3

Mill No.	Manufacturer	Mill type (1^0 /2^0 method)	Name	Infeed size mm (max)	Outfeed size µm (min)	Tip velocity (m/s)	Air flow m^3/hr (Adaptable yes/No)	Food Grade options	Drying options	Pot. to modify for flash drying (Yes/No)	Rates max.T/hr (evap T/hr)	Added Cooling (Yes/No)	Flexible (Yes/No)	Trial facilities available (Yes/No)	Added Size control (type)	Points of Interest/issue
49	Grenzebach Maschinenbau GmbH	Stator/Rotor (shear/impact)	Grenzebach BSH Whirlwind Mill	30	<100	117	9,600	Yes	Yes	Yes	10 (1.3 water)	No	Yes	?	No	2 Stages, wide Turbo-mill, air vol?
50	Fluid Energy Processing Equipment	Jet Mill (shear/impact)	Thermajet Flash Dryer	?	?	—	high?	Yes	Yes	Yes	(5 water)	No	Yes	Yes	Maybe	Size reduction? Air temps? Fat?
51	Fluid Energy Processing Equipment	Jet Mill (shear/impact)	Roto-jet Mill	<0.5	5	—	3,900	No	No	Yes	0.5	No	Yes	Yes	Yes (Int. classifier)	Similar to other classifier jet mills
52	Fluid Energy Processing Equipment	Jet Mill (shear/impact)	Micro-Jet Mill	?	0.5	—	6,950 air & 4,000 kg.hr steam	Yes	Yes	Yes	4.5	No	Yes	Yes	No	Uses high vol. of steam for finer grind
53	Fluid Energy Processing Equipment	Jet Mill (shear/impact)	Jet-O-Mizer	?	1	—	6,000 air & 6,800 kg.hr steam	Yes	Yes	Yes	9	No	Yes	Yes	Yes (Int. velocity)	Can use high vol. of steam but still dry - hi press. Steam
54	Bepex International LLC	Stator/Rotor (Impact/shear)	Pulvocron Dryer	?	1	~180	16,900	Yes	Yes	Maybe	?	Yes	Yes	Yes	Yes (Int. classifier)	Very large hp motors, efficiency?

6.3 Review of best potential operations with Mill-27 and through direct discussions with manufacturers.

From Table 2 the selected mills have been reviewed against Mill-27 key aspects from section 4.1 being:

- *Adjustable outlet gap/classifier, no static mill screen*
- *Very high speed (200 m/s) and frequency to maximise energy input*.
- *Very high air flow, at least 7.25 m3/hr of dry air for each kilogram of product feed*
- *Ability to form a differential pressure chamber to drive flashing*.
- *Mill cooling to maintain product temperature below 60 ºC*.
- *Flexible material milling operation*.
    a. Ability to have rate controlled in-feed (volumetric or mass)
    b. Hygienic design with simple and quick access for cleaning
    c. Fat friendly milled product recovery system (preventing fat solidification)
    d. Estimated flexibility to handle material types (bone, hide…)

Each of the mills has been rated out of 5 for each aspect, except for flexibility which has been rated out of 10 (spread appropriately across its four parts), these results are given in Table 3. Compared with Table 2 ratings, which were based on material, rate and specification requirements, there is not a large difference - with most of the higher rankings staying near the top. This is the result of none of these mills being of the same form as Mill-27, although both mills 1 and 38 go some way toward having a similar milling process (a blade swept annulus of product, rate and size controlled by a gap).

Though it is very probable that all of these mills in Table 3 will be able to stabilise red meat co-products effectively, and with much less development work than Mill-27, the mill manufacturers are hesitant to make any predictions prior to trials, especially given the moisture levels to be reduced. However it is more likely a rate issue than a feasibility one.

The choice should be from the top 5 mills in Table 3 if only to ensure an effective result. Other than this, efficiency, cost of equipment, technical support, ancillary support (turn-key ability) and willingness to adapt could be used to preference, but should be a decision of any subsequent project.

Size reduction prior to feeding the milling processes will be required, it is recommended that a system capable of taking any material (be it a femur bone or a complete hide) and reducing it to 5 mm would be sufficient. Such a system would include high speed knife cutters, like Pallmann's UltraGrannulator PS-C.

It is clear that Mill-27 is unique, in that it can form a “differential pressure cell” between its rotor blades, where the other mills can not as their rotors are not solid (Note that mills No: 1, 2 and 7 come close being solid but are still designed for turbulence rather than a pressure differential).

The fact that cavitation impacts energy transfer and size reduction has been shown[21] [22] [23] [24] . The concept of cavitation as a mechanism for aiding size reduction and drying, needs to be proven, as it may provide the foundation for efficient energy conversion, in a rapid manner with minimal functional damage. Adaptation of this to size reduction and drying design has not yet happened but could be completed through trials with mills 1, 2, 7 or 20 (CR only). This option would enable MLA to exploit this concept to its advantage without the constraints of Mill-27’s owners, as these are already commercial machines which can be purchased in a used state and adapted to test cavitation milling/drying.

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[21] Parag R. Gogate and A. M. Kabadi (2009). "A review of applications of cavitation in biochemical engineering/biotechnology." Biochemical Engineering Journal **44**: 60 - 72.

[22] Pinjari, D. V. and A. B. Pandit (2010). "Cavitation milling of natural cellulose to nanofibrils." Ultrasonics Sonochemistry **17**(5): 845-852.

[23] Shirgaonkar, I. Z., R. R. Lothe, et al. (1998). "Comments on the Mechanism of Microbial Cell Disruption in High-Pressure and High-Speed Devices." Biotechnology Progress **14**(4): 657-660.

[24] Schneider, B., A. Koşar, et al. (2007). "Hydrodynamic cavitation and boiling in refrigerant (R-123) flow inside microchannels." International Journal of Heat and Mass Transfer **50**(13–14): 2838-2854.

Table 3 Rating order for mills based on Mill-27 key aspects

Mill				Table 2	Mill 27 key aspects					Flexible material milling				
Mill N°	Manufacturer	Mill type (1^0 /2^0ary method)	Name	material, rate & specs for milling (10)	Adj Gap/ cassifier (5)	Speed & frequencey (5)	High air flow + 7,250 m^3/hr (5)	Differential pressure chamber (5)	Mill cooling <60 ºC (5)	Rate controlled infeed (1)	Hygenic simple quick cleaning (2)	Fat friendly (2)	Estimated material type flexibility (5)	Total out of 35
1	Bauermeister	Stator/Rotor (Impact/shear)	Gap Mill GM-D	6	4	3	2	2.5	5	0.5	1	1.5	3	**22.5**
38	Pallmann Maschinenfabrik GmbH & Co.	Stator/Rotor (Impact/shear)	Turbo Mill REF (or PP)	7.5	4	2.5	3	3	3	1	2	1	3	**22.5**
39	Pallmann Maschinenfabrik GmbH & Co.	Rotor beater/stator (shear/impact)	Contra Selector Mill PPSR	6	3	2.5	3.5	2	3	1	2	2	3.5	**22.5**
4	Mahltechnik Gorgens GmbH	Stator/Rotor (shear/impact)	Turborotor	8	3	3.5	5	1.5	2	1	0	1.5	3	**20.5**
54	Bepex International LLC	Stator/Rotor (Impact/shear)	Pulvocron Dryer	6.5	3	3	3	1	3	1	2	1	3	**20**
31	Precision Products	Rotor beater/stator	Turbo Classifier Mill	6.5	3	2	3	2	3	1	1	1	3	**19**
16	IPEC	Stator/Rotor (shear/impact)	Rotormill	7	3	3.5	4	1.5	1	1	0.5	1	3	**18.5**
46	Hosokawa Alpine	Stator/Rotor (shear/impact)	Alpine Long Gap Mill (LGM)	7	3	2	4	2.5	1	1	1	1	3	**18.5**
37	Pallmann Maschinenfabrik GmbH & Co.	Stator/Rotor (Impact/shear)	TurboFiner PLM	6	2	3	2	2	3	1	1	1	3	**18**
33	Poittemill Group	Stator/Rotor (shear/impact)	Attrimill	6	2	2	2	2	1	1	1	1	3	**15**
35	Poittemill Group	Stator/Rotor (Impact/shear)	Integrated Classifier Mill	6.5	3	2	2	1	1	1	1	1	3	**15**
29	Shanghai Zhengyuan Powder R&D Co Ltd	Stator/Rotor (shear/impact)	Super Rotor Mill LHW 3000	6	2	2	2	2	1	1	0	1	2.5	**13.5**
53	Fluid Energy Processing Equipment	Jet Mill (shear/impact)	Jet-O-Mizer	7	2	2	3	1	1	1	1	0	2	**13**

Note: Mill 1 has been assessed to have limited availability for added air flow, although a patent including this process indicated that this may be possible US Pat 6,136,366. It is easy to add an external classifier which would solve this limitation – but for this exercise this was not done if not specified as part of the process.

7 Conclusions and recommendations

The identification and characterisation of the key milling aspects for Mill-27 have been proposed as: an adjustable outlet gap/classifier with no static screen, a very high rotor tip speed (200 m/s) and frequency which maximises energy input, a high air flow of at least 7.25 m3/hr of dry air per kilogram of feed, an ability to form a ‘differential pressure chamber’ to drive flash drying, an ability to maintain product temperature below 60 ºC and an ability to provide flexible material milling in one arrangement.

Existing milling operations have been identified and reviewed with a summary list of 54 mills being rated and selected as having potential to stabilise red meat co-products through meeting requirements based on material, rate and product specification. This list has been reduced through selecting those rating in the top 25%, resulting in 13 mills which have been further rated and ordered against Mill-27’s key aspects.

It has been concluded that any of the 13 mills would provide a viable solution to stabilising red meat co-products, requiring less development than Mill-27. It is proposed that the top 5 mills be considered as this will ensure a more effective result.

It is recommended that a project be initiated to evaluate, trial and select the best of these 5 mills with a range of co-products, including a cost benefits analysis and that this be done in association with an MLA stakeholder if possible. Following the success of these proposed trials at a manufacturers test facility a production/pilot system could be commissioned and output products used to develop the potential market opportunities.

It is also recommended that the concept of cavitation as a mechanism for aiding size reduction and drying design be proven. This would enable MLA to exploit this concept to its advantage (patent) without the constraints of Mill-27’s owners, through adapting commercially available equipment identified in this review and testing in a rigorous scientific manner. However a focus on the stabilising of these co-products should have precedence, as this alternative, more efficient milling/drying process will then have more justification for funding.

8 Success in achieving objectives

This project has successfully identified a considerable number of milling processes (up to 54) with the potential to stabilise red meat co-products. The project has further assessed these processes enabling a small number of mills (5) to be identified as having the potential to provide the most effective results. Some mills will perform better than others with different co-products, but a trial based evaluation will be necessary to quantify this, and is available through the manufactures testing facilities.

No mills were found to match Mill-27, but several have been identified as being able to be adapted to evaluate the concept of cavitation milling/drying which is proposed as a possible mechanism for Mill-27's performance.

9 Impact on meat and livestock industry – Now and in five years time

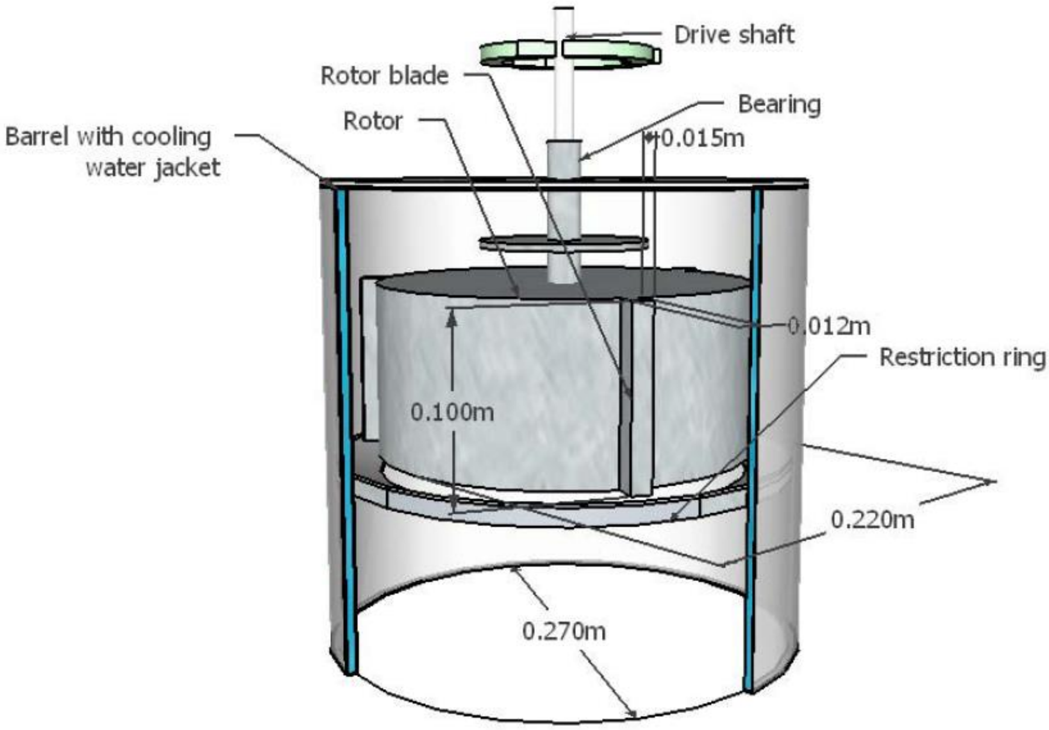
In the short term these developments will enable the characterisation and cost benefits of potential markets for these stabilised co-products, while enabling the necessary information for stakeholders to plan for capital investments to realise these benefits. The applications of powders are expected in: extraction for bioactives; in restructured meat products; in novel textured products such as meat noodles or meat sprinkles; in processed food products; in stabilisation of materials for transport to centralised rendering; and in dewatering alternative fuels for boilers in processing operations.

Over the five year time frame it is expected these processes would be providing returns to stakeholders through ensuring that value of co-products is maximised by maintaining functionality of the materials through stabilisation. This project has identified that technologies exist today which should fulfill the requirements for stabilising co-products and that minimal development is required to evaluate this as a reality.

10 Appendices

10.1 Appendix 1: Calculated maximum retention time and rotor bar frequency of Mill-27

Fig A1 Sketch of Mill-27 key features



From the above figure the Mill-27 operating volume when fill is:

The cylindrical volume of the Barrel over the height of the rotor, minus the volume of the cylinder made by the rotor with its blades. This is calculated below as:

Operating volume $= ((\pi * (0.27/2)^2) – (\pi * ((0.22+(2*0.015))/2)^2)) * 0.1$

$= 8.17 \times 10^{-4}$

= 0.817 litres

If we feed co-products at 12 kg/hr (average trial results) then using the estimated milled material density - for example Trim, which at: 70% water (ρ = 1 kg/l), 20% protein (ρ = 1.35 kg/l) and 10% fat (ρ = 0.65 kg/l) has a calculated density of around 1.035 kg/l we get:

Volumetric feed rate = 12 /1.035 = 11.6 l/hr

This gives a max retention time 0.817/(11.6 l/hr/(3600 sec/hr)) = 253 sec.

= 4 min 13 sec

The Mill-27 was run between 16,000 and 20,000 rpm giving a rotor tip frequency of 48,000 to 60,000 (i.e. 3 rotor tips per rev.). From the above figure the velocity of the rotor bar tip can be calculated as:

Rotor tip speed = rpm * tip circumference = rpm * πd_{tip} = (rpm* 0.785 m/min).

Hence Rotor tip speed ran between 12,560 and 15,700 m/min or 754 to 942 km/hr

10.2 Appendix 2: Air flow requirements

Minimum air flow required to carry moisture removed

Lung trials resulted in the highest 'kg of moisture removed /kg of feed' for the co-products investigated, so is used here to determine the minimum air flow needed to carry the moisture out of the system.

The feed rate of lung was 12 kg/hr and the temperature of the outlet air was 50 ºC. The side channel blower used to boost the air flow (Unijet1000 with 15 kW drive) typically delivers 700 m^3/hr of air[25].

From 'high temperature psychrometric charts' air at 50 ºC can carry around 0.086kg of moisture/kg of dry air (i.e. the saturation point) and has a mass volume of 1.04 m^3/kg of dry air [26]. Hence as we removed 7.2 kg/hr of water from the lung material we would need:

Dry air req'd m^3/hr = (7.2 kg moist/0.086 kg moist/kg dry air)* 1.04 m^3/kg of dry air

= 87 m^3/hr of dry air

The volume of air used 700 m^3/hr was excessive, however as indicated earlier the feed rate of material to the mill was likely too low, resulting in the low residence times observed. Had the rate been 5 to 10 times higher the cross channel blower would have been well sized.

For a production type machine that could process around 1000 kg/hr, an air flow around:

Production air req'd m^3/hr = (1000kg/hr / 12) * 87 m^3/hr

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[25] Anon. "Industrial Blowers - Performance Graphs, ESAM Air Technology ". Retrieved 24 April 2012, from http://www.sidechannelblowers.com.au/blowers/graph#vacuum.

[26] Earle, R. L., Ed. (1983). Unit Operations in Food Processing. APPENDIX 9 (b), New Zealand Institute of Food Science and Technology Inc.

$= 7250\ m^3/hr$

$\approx 2\ m^3/s$ of dry air

This is the minimum air flow required to carry the moisture being removed, obviously with lungs even more moisture needed to be removed to get to the desired a_w but this is yet to be determined. However this does give an indication of the air flows required with production sized equipment.

Operational air velocity

The velocity of the air through the 3 chambers bordered by the product, rotor blades and the rotor body of the mill (see Figure 2) is also high, calculated as follows:

Operational air velocity = Total air flow/cross sectional area of 3 chambers

$= (87\ m^3/s\ /\ 3600\ s/hr)\ /\ 0.01069\ m^2$

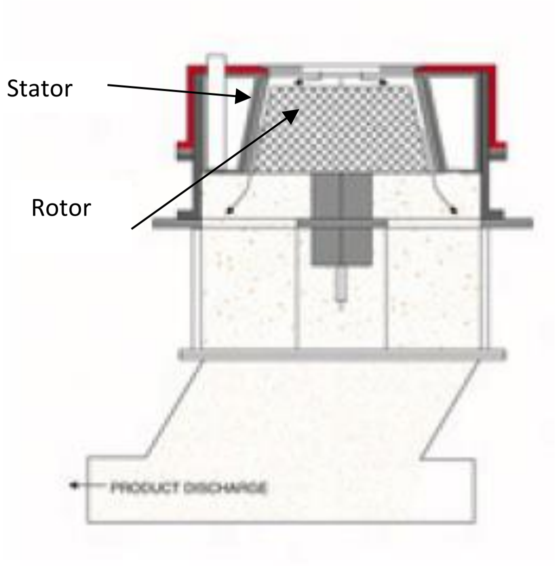
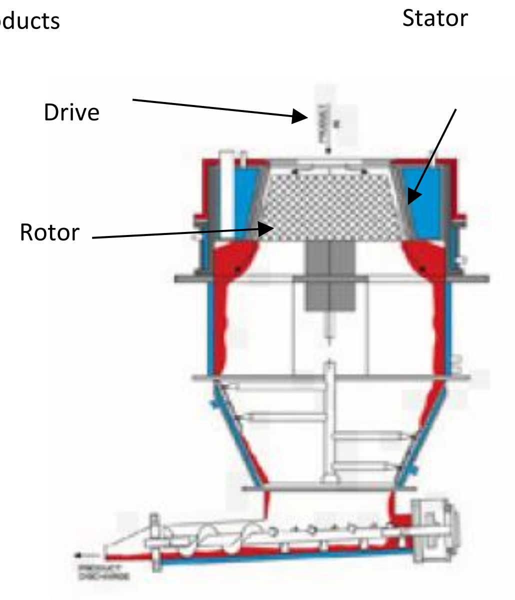
$= 2.3\ m/s$

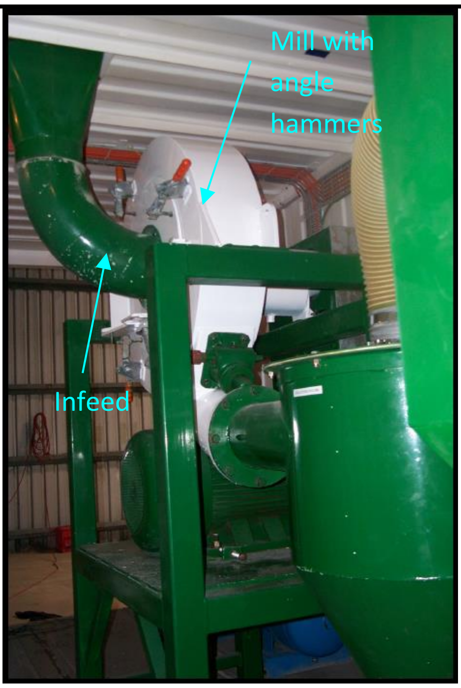
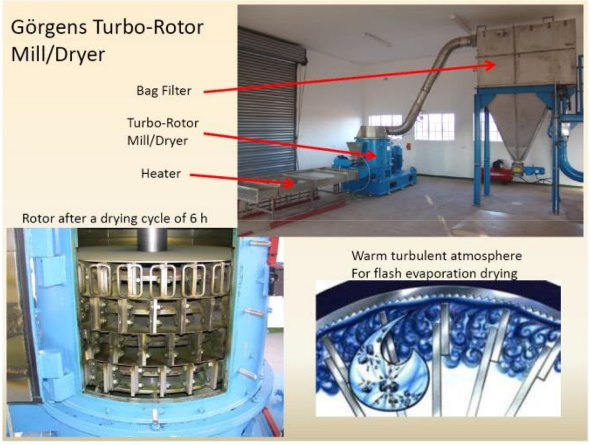
Conveying consideration

Most food materials are conveyed effectively with in pipe velocities of up to 25.4 m/s, with the above flow rate of 2 m^3/s there is no risk of product settling in the pipes (i.e. with a 0.20 m diameter pipe, pipe velocity will be over 60 m/s.

10.3 Appendix 3: Schematics of mill options in Table 2

The following schematics are to give an appreciation of the various processes and an indication of their similarity/difference to Mill-27. In reviewing each process the following has been assessed; ability to handle 'fatty', 'wet' & 'sticky', rotor tip speed, ability to handle additional air if required, additional cooling, if they can be used for drying, what rate they can handle, if there are test facilities we can use, the maximum size that can be feed, the minimum size that can be achieved, if there is any out-feed size control and any additional points that may be of interest or issue.

<table>
<tr>
<td>1. Gap Mill GM-D – fine grinding of solids
</td>
<td>2. Gap Mill GM-P - used for making ultrafine pastes from products
</td>
</tr>
<tr>
<td>3. Alligrator - for fine grinding of wheat or bone (uniquely center feed hammer mill)</td>
<td>4. Gorgens Turborotor Mill/Dryer – being used to mill and dry seaweed as part of microalgal biotechnology</td>
</tr>
</table>

	
5. Ultrafine Pulverizer – used for Guar gum production, 10 to 400 hp (horizontal or vertical mill arrangements	6. Buhler Unimill – used for size reduction of cocoa shells to liquefaction of pre-reduced cocoa mass blocks.
	
7. Nisshin Super Rotor Mill – Design close to Mill-27	8. Nisshin Super jet Mill Used for Pharmaceuticals and Toners

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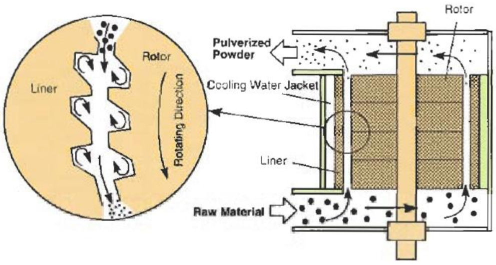
<td>


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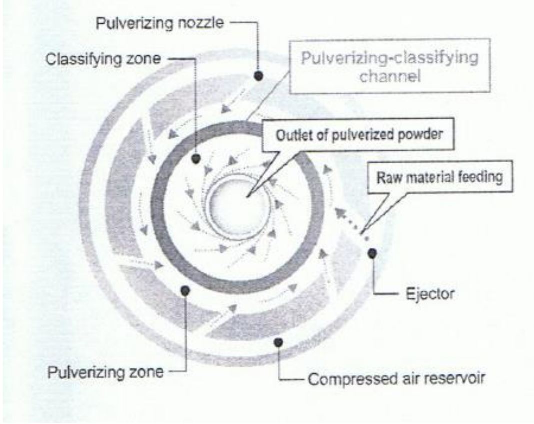
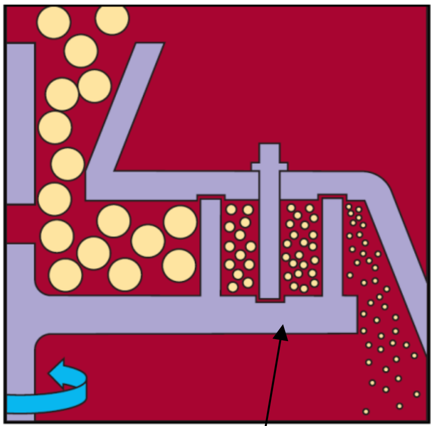
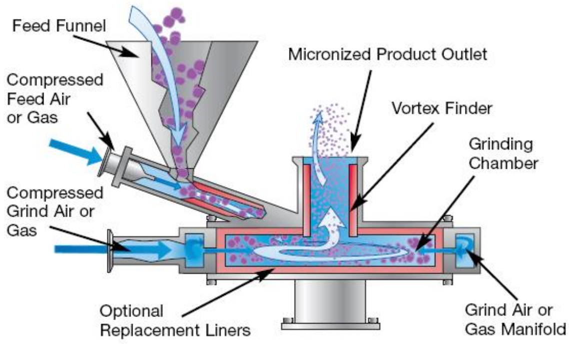
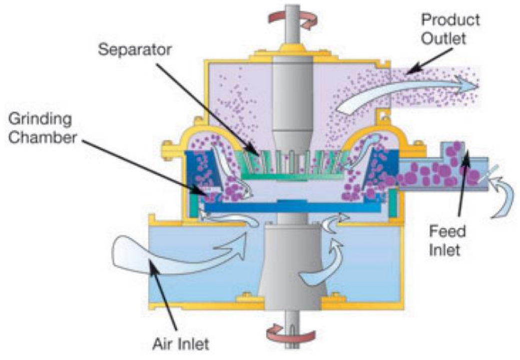


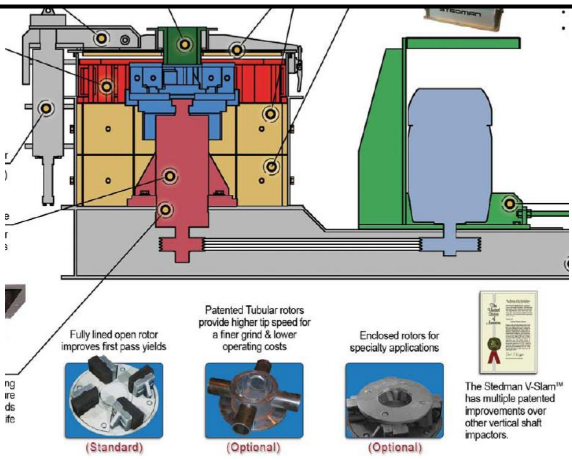
</td>
</tr>
<tr>
<td>9. Sturtevant Pin Mill – High impact Mill used for wet and dry friable material (eg bone)</td>
<td>10. Sturtevant Micronizer Jet Mill – mainly attrition (shear)</td>
</tr>
<tr>
<td>

Use block rotor

</td>
<td>


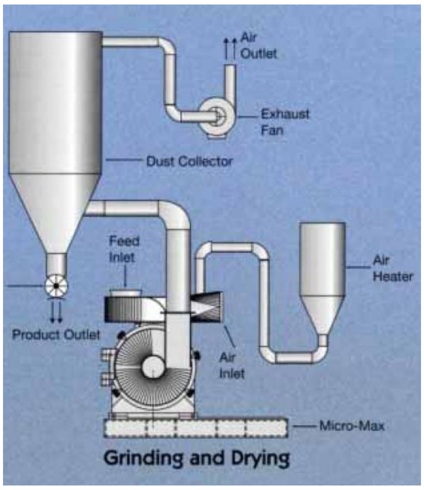
</td>
</tr>
<tr>
<td>11. Sturtevant Powderizer – Used mainly for friable materials (may be modified)</td>
<td>12. VSlam vertical shaft impactors – normally used for minerals but also poultry meal and rendering (may be modified)</td>
</tr>
</table>



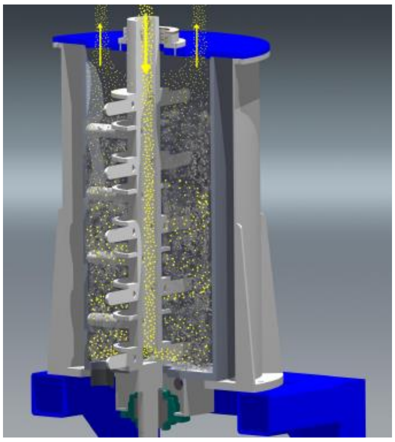
13. Micro-max - mainly for friable materials but is adaptable



14. *ufg* Mill – is a dry air-swept media mill (feed material must be able to be pneumatically conveyed)



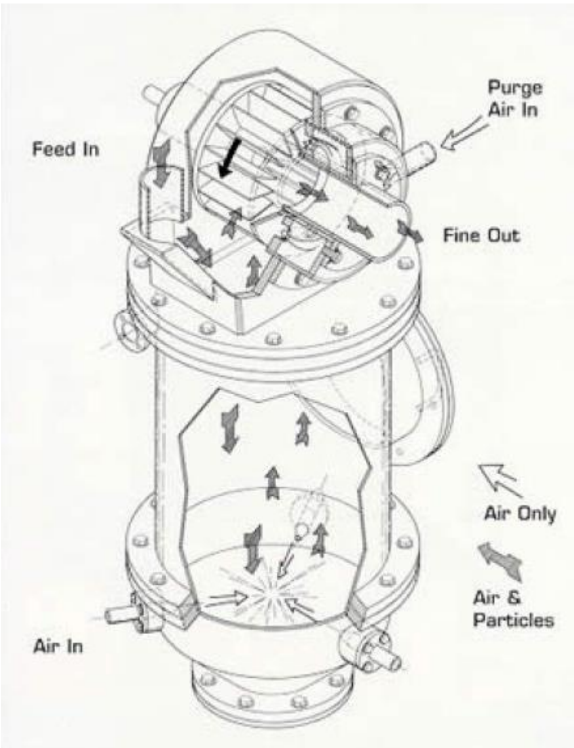
15. RSG Hammer Mill – In-line system using ext classifier to return oversize (mainly impact) for friable material

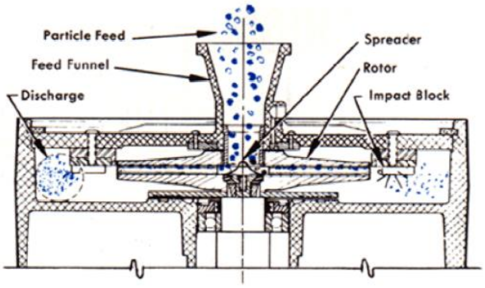


16. IPEC Rotormill Used for anything from algae to insulation materials - handles fibrous materials (in essence a turbo-mill)

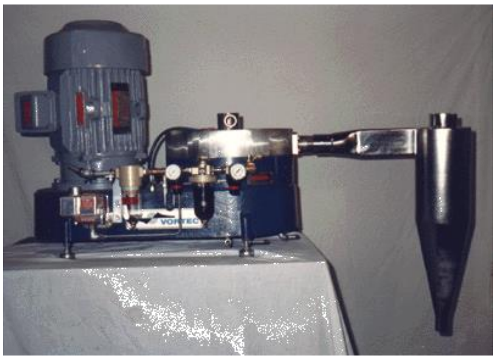
17. Dense Phase Jet Mill – mainly used for toners and very fine powder markets

18. Vortec M1 Impact Mill – Efficient impacting, every particle impacts once then is classified and oversize returned.



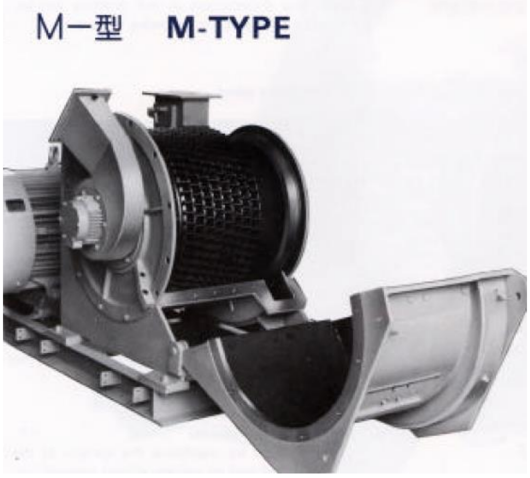
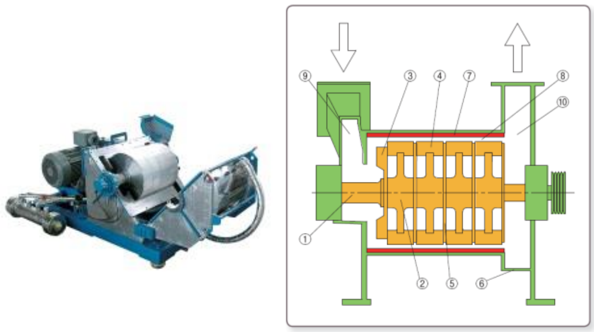
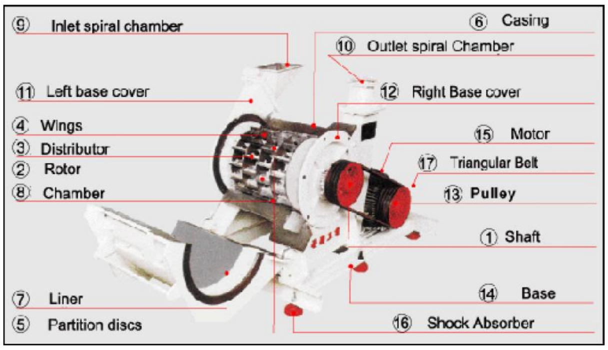
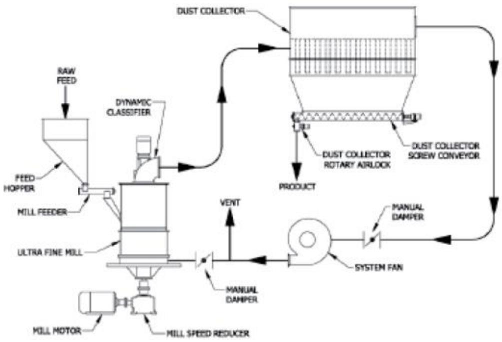


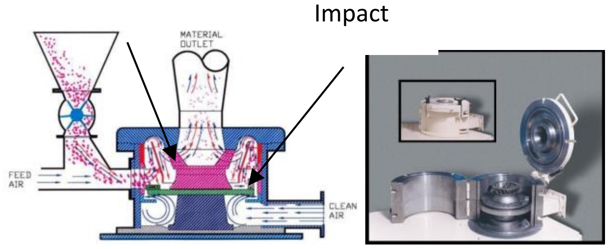
M1 with C1-cyclone – Mainly used for impact grinding of minerals and chemicals, uses cryo. For fibrous.

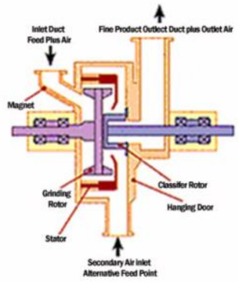
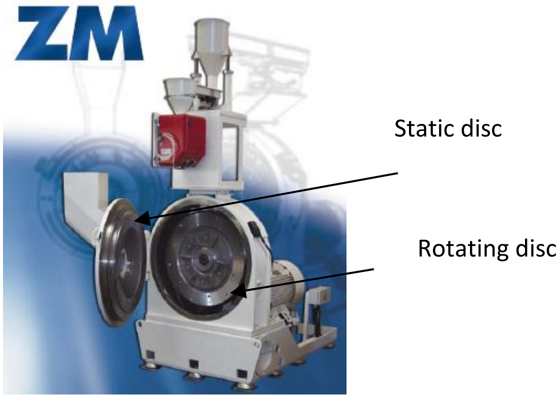
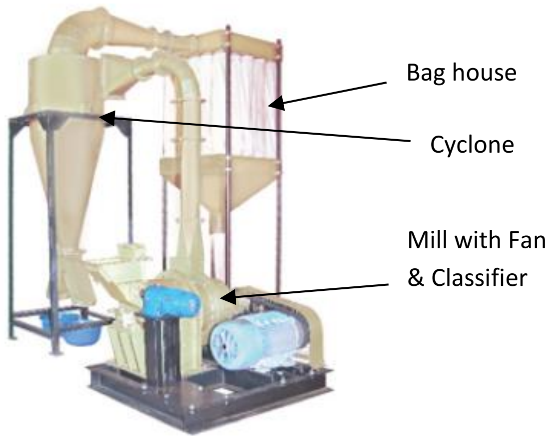


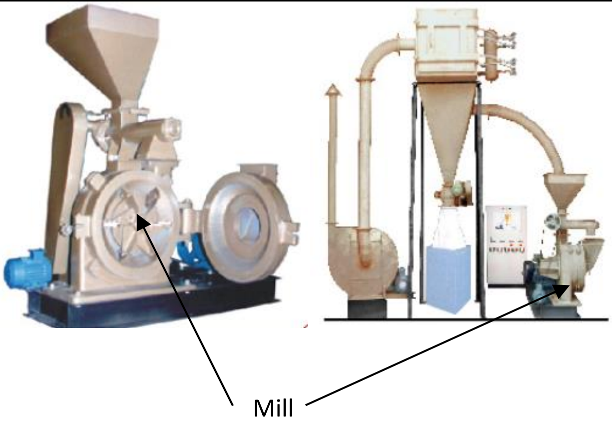
19. Freund Turbo Corporation Turbo Mills S & M – used for food and chemical, similar to other Turbo Mills except M has finer blades

20. Freund Turbo Corporation Turbo Mill E, R & CR – Can have multiple rotors up to 8. Similar to Mill-27 (only horizontal)

<table>
<tr>
<td>
</td>
<td>
1-Shaft 2-Rotor 3-Distributor 4-Blades 5-Spacer 6-Casing 7-Grooves 8-Mill chamber 9-Inlet scroll chamber 10-Outlet scroll chamber</td>
</tr>
<tr>
<td>21 Mill Powder Tech Solutions Turbo-Mills – used for food, chemical & recycling, similar to other Turbo Mills.

</td>
<td>22. Alstom Power Raymond Ultra Fine Mill – high rates & fine grind but of ring mill design.

</td>
</tr>
<tr>
<td>23. Air products PolarFit Ultra fine grinding Mill – used for pharmaceuticals and spices, uses liquid nitrogen to control temperature.

Impact
Shear
Classifier</td>
<td>24.CMS Air Swept Classifier Mill mainly impact but can accommodate high air flows. Used for a very wide range of food products from flavours to fibre.
Classifier
Impact

</td>
</tr>
<tr>
<td>25. British Rema Rotary Air Classifier Mill – Wide range of products including food and pharmaceutical, good air flow.</td>
<td>26. British Rema Rotary Impact Mill – versatile but limited in size reduc Use just ens but can run without
Beater</td>
</tr>
</table>

<table>
<tr>
<td> 
</td>
<td> </td>
</tr>
<tr>
<td>27.Ningbo MS60K Abrasive Disc Starch Mill – used for a range of foods
</td>
<td>28. Neue Herbold ZM 800 Pulverizer – used for plastics has a static and a rotating disc

</td>
</tr>
<tr>
<td>29. Zhengyuan Powder Super Rotor Mill LHW 2000 – used for food and fibre (similar to other turbo mills, but cheap)
</td>
<td>30. Precision Products Wizzon Mill – used for food, chemicals and pharmaceuticals.

</td>
</tr>
<tr>
<td>31. Precision Products Turbo Classifier Mill – used for food, chemical and pharmaceutical, adaptable for increased air flow and drying</td>
<td>32. Precision Products Whirlpul Micronizer – used for fine grinding of guar, process appears a mix of Turbo-mills and Mill-27.</td>
</tr>
</table>

<table>
<tr>
<td>
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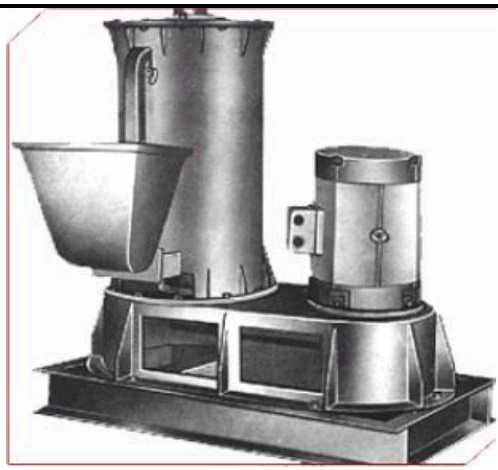
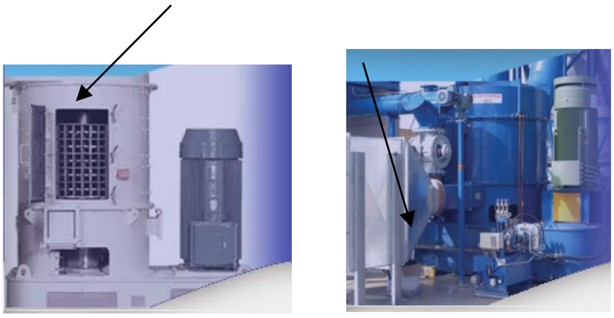
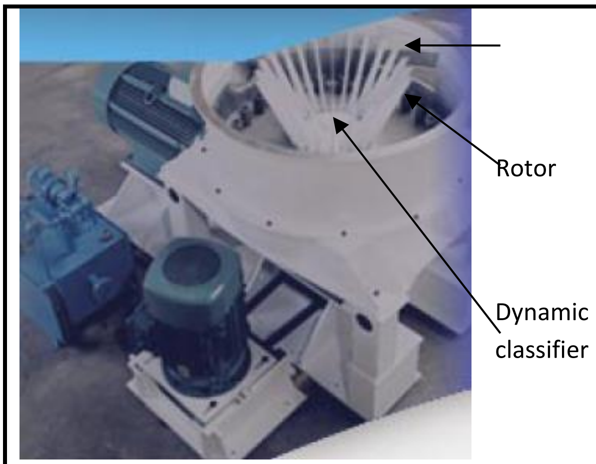
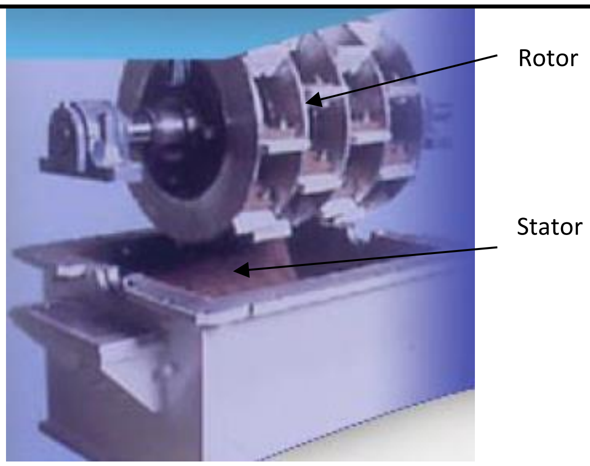
<td></td>
</tr>
<tr>
<td>33. Poittemill Group Attrimill – used for plastics and food, similar to other Turbo mills, but very high rates.</td>
<td>34. Poittemill Group Fluidised Bed Air Jet Mill – used for food, chemicals and minerals.</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>35. Poittemill Group Integrated Classifier Mill – used for foods, pharmaceuticals and minerals for grinding drying.</td>
<td>36. Poittemill Group High Yield Pulverizer used for food and minerals, essentially a crusher of Turbo-mill design.</td>
</tr>
</table>

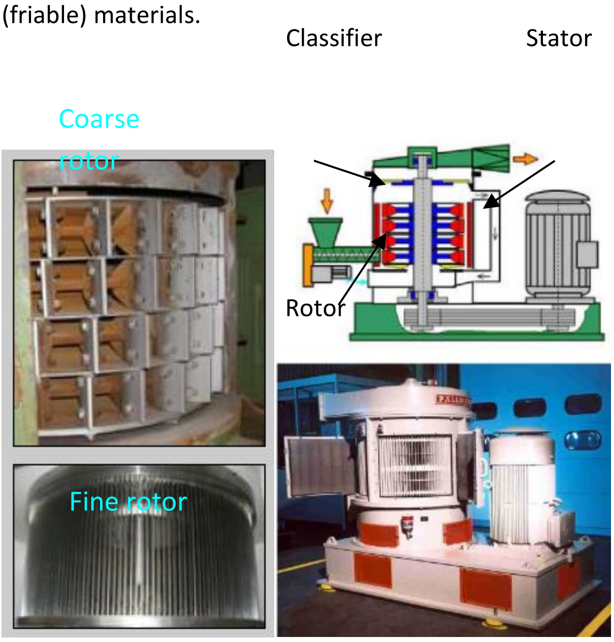
Static
classifier
bar

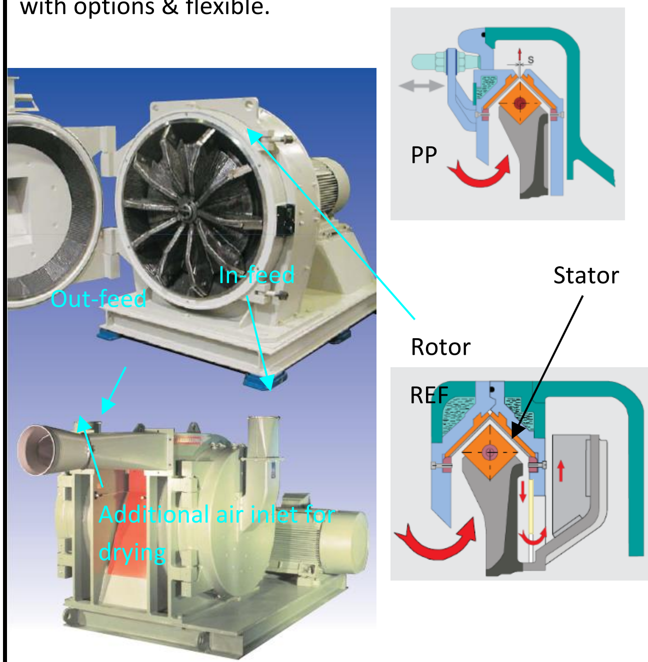




37. Pallmann TurboFiner PLM – used for pharmaceuticals, food, chemicals and minerals handle elastic and brittle (friable) materials.

38. Pallmann Turbo Mill REF or PP – used for food, chemical and pharmaceuticals with options & flexible.

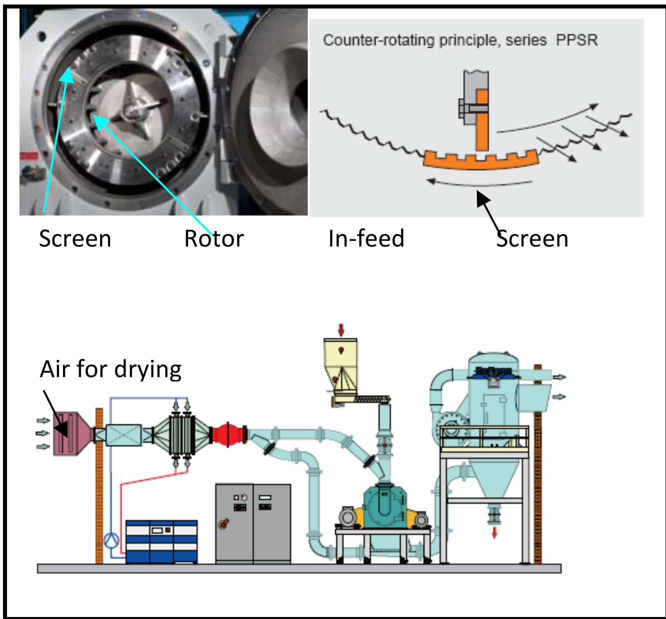


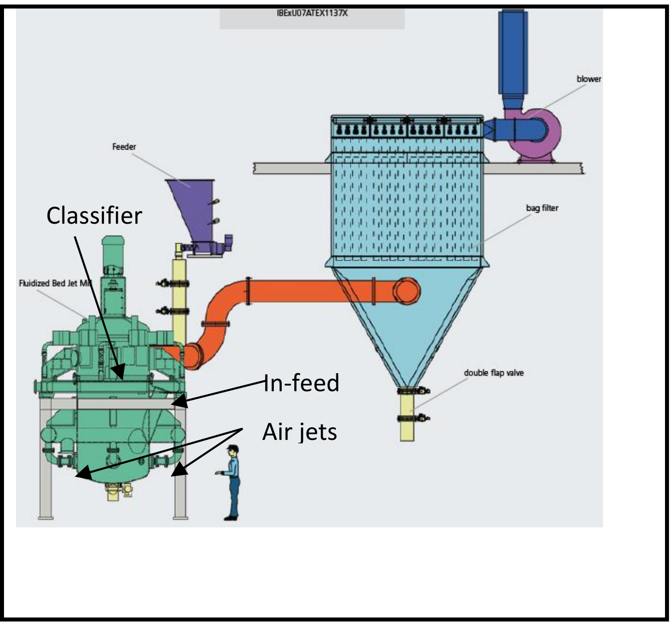


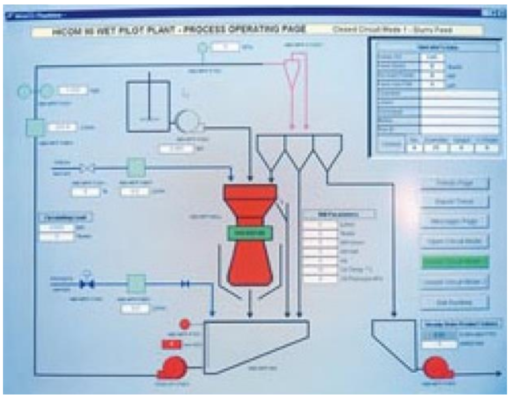
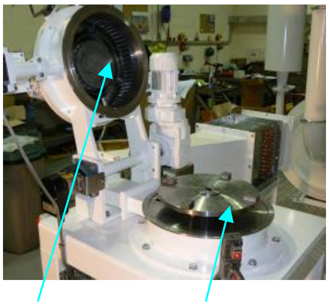
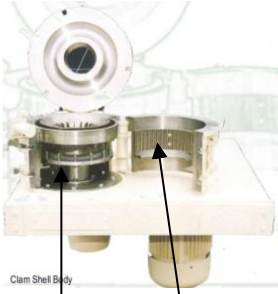
39. Pallmann Contra-Selector PPSR – used for fine grind of fat-wet-sticky foods with a drying option.

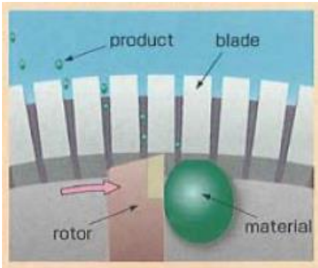
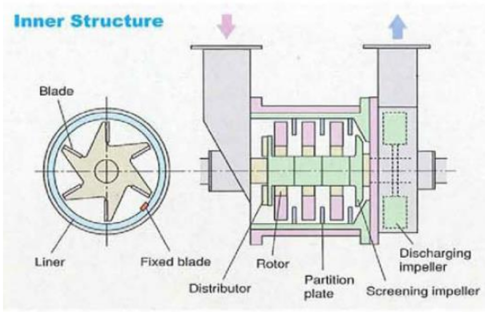
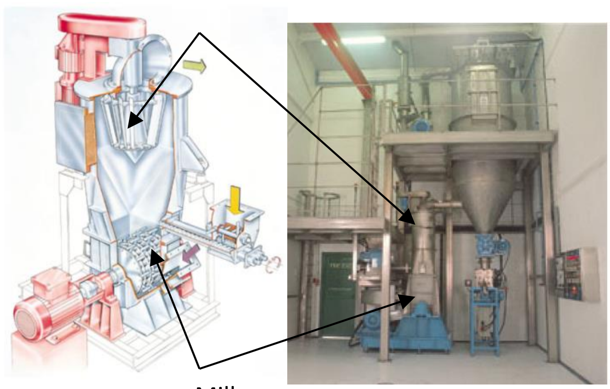
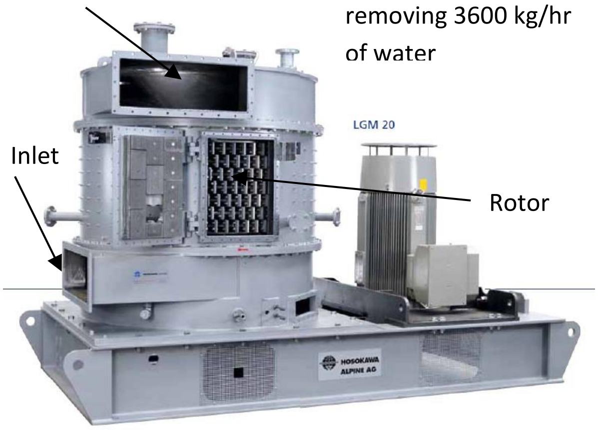
40. Netzsch-Condux, Condux Fluidized Bed Jet Mill CGS – used for pharmaceuticals and food.

REF

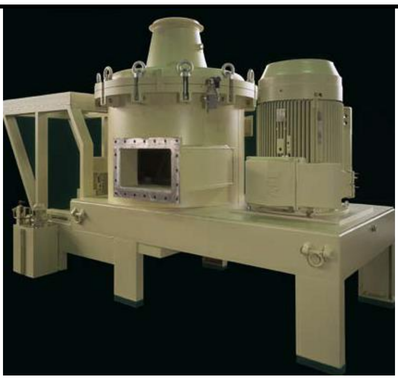

Counter-rotating principle, series PPSR
Screen
Rotor
In-feed
Screen
Air for drying


Classifier
Feeder
blower
bag filter
Fluidized Bed Jet Mill
double flap valve
In-feed
Air jets

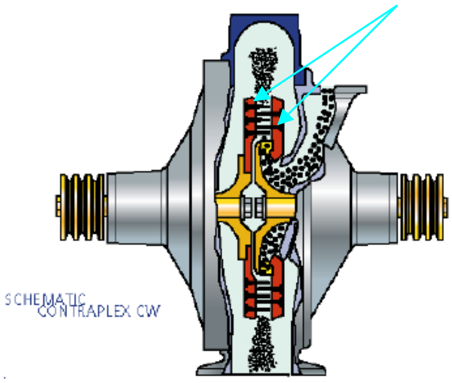
<table>
<tr>
<td>41. Ludowici Hicom Mill – used autogenously or with media for ore particularly diamonds, vertical axis rotation in conical pendulum generates up to 50 G.
</td>
<td>42. KEK-Gardener PPS Air Classifier Mill – used for pharmaceuticals, food and chemical with flexible design layouts.

Classifier Rotor Rotor Stator opens for cleaning</td>
</tr>
<tr>
<td>43. Masuko Sangyo Micro-Meister Mill – used for food and pharmaceuticals can operate as a cutter/shearing mill and a disc style grinder but no drying (can cut down to 20µm?).</td>
<td>44. Masuko Sangyo Ceren Miller ultra fine microniser – used for chemical and food, slightly different to other turbo-mills</td>
</tr>
</table>

  Head Options  Cutting Head  Grinder (option)  Basket Cutting Head	 
45. Hosokawa Micron Flash Dryer – used for food products, very small foot-print.	46. Hosokawa Alpine Long Gap Mill (≡Turbo Mill) (LGM) – used for food, chemicals, recycling and minerals, also drying (very large air capability)
Classifier  Mill	outlet This unit capable of removing 3600 kg/hr of water Inlet  Rotor
47. Hosokawa Micron Mikro Mak – used for fibrous products like wood	48. Hosokawa Alpine Contraplex Pin Mill CW – used for food, recyclables, chemicals and minerals, high impact.

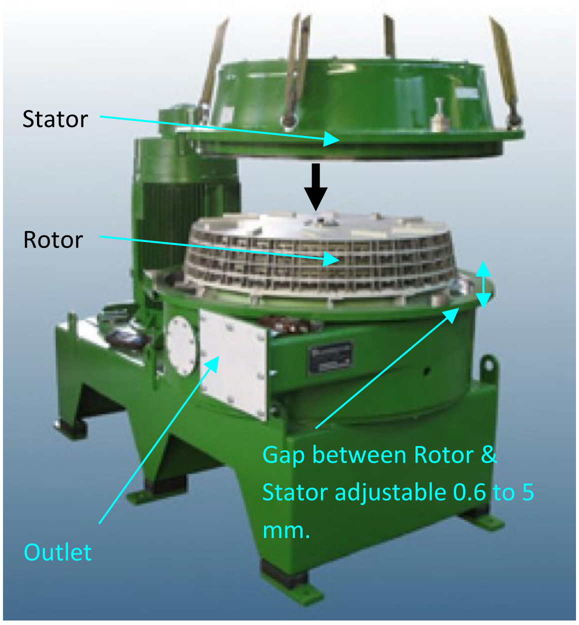
Two rotors with intermeshing pins rotating in opposite directions



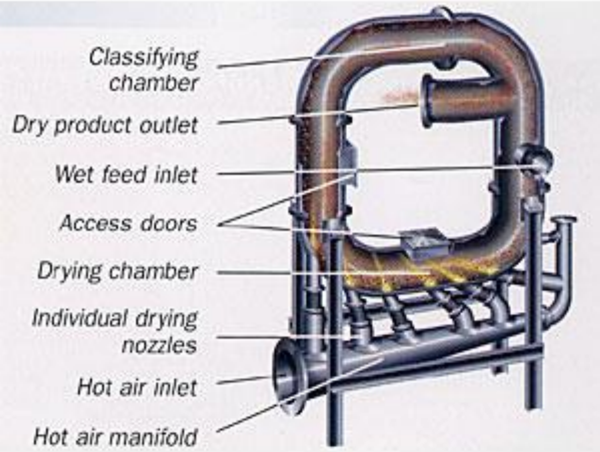
49. Grenzebach BSH Whirlwind Mill – used for food, chemical, and recycle with option for drying.



50. Fluid Energy PE Thermajet Flash Dryer – used for a wide range of applications including food

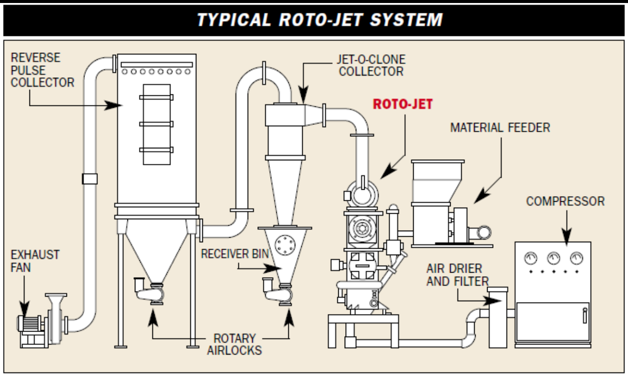
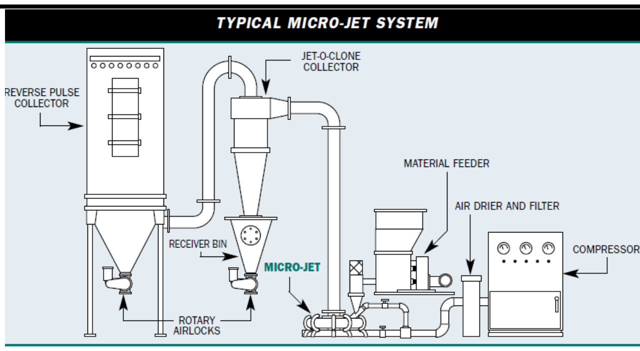
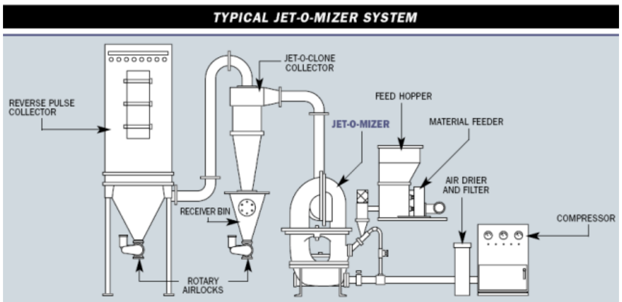
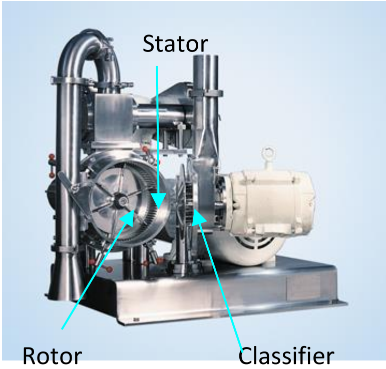
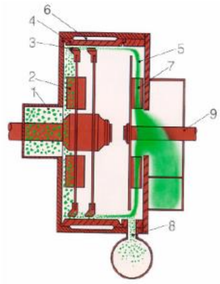


51. Fluid Energy PE Roto-jet Mill – used for fine grinding of minerals, organics, plastics and food & pharmaceutical.



Used for drying soy-cake from 80% to 12 % with little denaturation (normally significant denaturation occurs around 125 ºC). Process uses 1000 ºC inlet and 250 ºC outlet air temperatures)

52. Fluid Energy PE Micro-jet – used for food, pharmaceuticals and chemical applications.

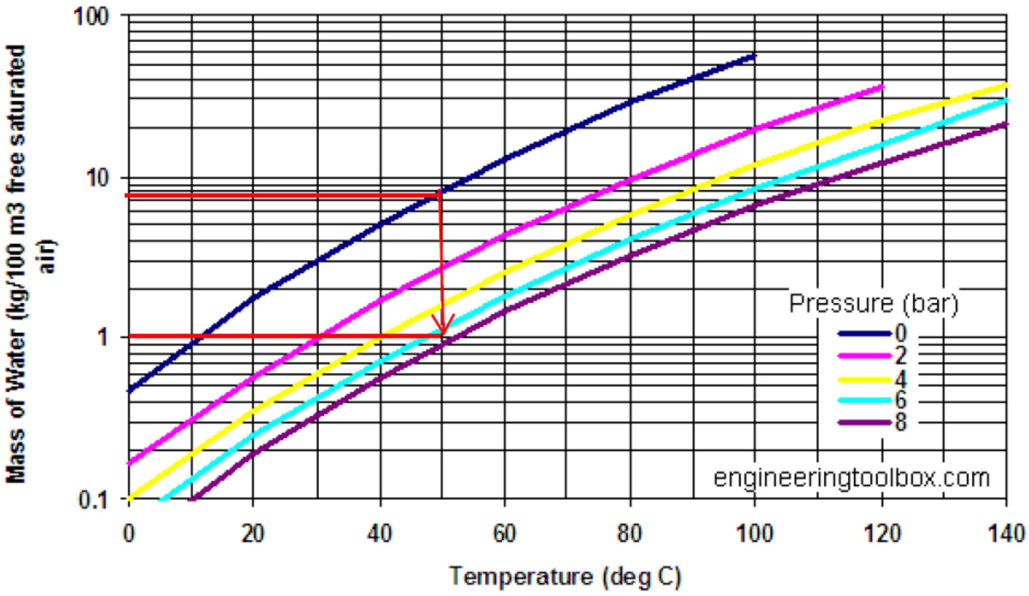
	
53. Fluid Energy PE Jet-O-Mizer – used for plastics, foods, pharmaceuticals, chemicals and ores 	54. Bepex Pulvocron® PULVERIZER DRYER – used for moderate moisture reduction and fine size reduction.   1. In-feed 2. Primary beaters 3. Secondary beaters 4. Stator liner 5. Classifying zone 6. Cooling jacket 7. Classifier 8. Oversize return tailings port 9. Adjustable classifier speed

10.4 Appendix 4 Variation in water carrying capacity of air at different pressures[27]

[27] (2012). "Pressure and Maximum Content of Water in Saturated Air." from http://www.engineeringtoolbox.com/water-content-compressed-air-d_1275.html.

The maximum water content in saturated air depends on air pressure and temperature.

Gauge Pressure in bar



From the above chart it is clear that increasing the pressure from atmospheric (0 bar gauge) to 100 psi (6.8 bar gauge), the pressure a number of jet mills operate at, results in a substantial reduction in water carrying capacity of the air. From 7.5 to 1 kg/100 m^3, this defeats the drying purpose and results in 7.5 times the air needed which is already very expensive having been compressed.

Mills operating at these pressures at the outlet will not be considered. However if the mills reduce the pressure at the outlet the increase in volume will consume any free water rapidly, these mills will be considered.

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