Review Article

Engineering Aspect of Low-Medium Pressure Pressed Agglomeration Process

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ABSTRACT

Agglomeration processes are used for various purposes such as conditioning of raw materials, shaping, blending with filling materials, dressing of wastes for recycling, production and refinement of finished product. Agglomeration has a wide range of applications in the pharmaceutical industry. It can be used to produce homogeneous mixtures, granules and pellets of API's and excipients to ensure a stable solid dosage form with defined properties. There are different types of agglomeration processes, however, it is imperative that economy of the process must be achieved and hence extrusion agglomeration process becomes the choice. There are several different styles of extruders available in the market. This may cause difficulty for pharmaceutical manufacturers to select a proper extruder for production of agglomerated products. During extrusion agglomeration, a number of functions occur in short time, i.e. conveying, mixing, homogenization, deaeration, heating/cooling, forming/shaping, expansion and texturization. This suggests that a thorough understanding of the design of extruders and their operation becomes essential. In pharmaceutical industry screw extruders are widely used and hence in this review a detailed understanding on design and operation of screw extruder is provided.

Keywords: Pressure agglomeration, agglomeration extrusion, single screw extruder, twin screw extruder, extrusion process variables.

INTRODUCTION

Agglomerated particle materials are frequently used for convenience during transportation, handling, processing and for pharmaceutical or food or agricultural formulations. Agglomeration has a wide range of applications in the pharmaceutical industry. It can be used to produce homogeneous mixtures, granules and pellets of API's and excipients to ensure a stable solid dosage form with defined properties.

Agglomerated powders are generally characterized in terms of size, shape, interaction to temperature and moisture and their functionality. Agglomeration is the binding of fine powder particles to form a large porous structure. Agglomeration is a term used to describe the size enlargement process where single particles become bonded to form a product with larger mean particle size. In short, agglomeration is a process in which physical or chemical forces causes sticking of particulate solids. The process of agglomeration is triggered by either specific processing condition or by adding binders and other substances that cause adherence of solids by forming bridges between the particles.

The agglomeration processes are classified by the principal mechanisms (table 1) by which the particles are made to come close together[1].

Different types of agglomeration processes are described as follows:[2]

Growth Agglomeration: Growth agglomeration occurs in conjunction with unit operation like granulation, agitation and mixing. Growth agglomeration process is similar to natural agglomeration process where particle to particle adhesion is achieved by addition of liquid and binders depending on the properties of the particles to be agglomerated. The particle size enlargement occurs by coalescence or aggregation based on cohesive force (Vander walls force). The equipment used for this type of agglomeration process includes rotary drums, pans, pin mixer, ribbon mixer, flow jet mixing system etc.

Particle Agglomeration: Particle agglomeration occurs in conjunction unit operations like droplet agglomeration or surface agglomeration. In droplet agglomeration the particles are wetted with the help of drop of liquids (of binder material) and added to fluidized column drop wise by spraying In surface agglomeration steam or moist air (with relative high humidity) is passed through particles resulting into wetting of particles (due to condensation) and the stickiness (the driving force) causes the particles to agglomerate. The equipment used for this type of agglomeration includes spray dryers and fluidized bed granulators.

Pressure Agglomeration: Pressure agglomeration occurs in conjunction with unit operation like compression. In pressure agglomeration initially there is forced rearrangement of particles due to applied compressive force followed by breaking of brittle particles with increase in pressure. Equipments used for this type of agglomeration includes mould press, tablet press and roll press. Another type of pressure agglomeration is extrusion agglomeration where a powder mixture is blended with binder liquid and then extruded at low pressure followed by drying and crumbling. The

equipment used for this type of agglomeration includes low-medium pressure extruders including screen and screw extruder. Low-medium Pressure agglomeration has wide application in industry.

Low-medium pressure extrusion agglomeration is increasingly important in pharmaceutical industry for transforming the material mix into intermediate or finished products[3]. However, literature survey has revealed that many fundamental aspects of low pressure process of extrusion agglomeration are poorly understood in pharmaceutical field. There are several different styles of extruders available in the market. This may cause difficulty for pharmaceutical manufacturers to select a proper extruder for production of agglomerated products. During extrusion agglomeration, a number of functions occur in short time, i.e. conveying, mixing, homogenization, de-aeration, heating/cooling, forming/shaping, expansion and texturization. This suggests that a thorough understanding of the design of extruders and their operation becomes essential. In pharmaceutical industry screw extruders are widely used and hence in this review a detailed understanding on design and operation of screw extruder is provided.

Table 1: Mechanism of Agglomeration Process

S. No.	Mechanism	Highlights
1.	Vander walls attraction	These are weak forces that have very limited range of interaction. To observe its force particles need to be very close to each other and the separation distance should be minimum.
2.	Capillary forces	It is a function of surface tension, the size of particles and the separation distance. This force is applicable when wet particles are interacting with each other. The wetness of particles reduces the surface tension and the adhesive forces become stronger than the cohesive force causing the particles to agglomerate.
3.	Electrostatic agglomeration	This is applied to stabilized solution by applying alternating electric field. This results into particle oscillation or collision with varying amplitudes and velocities depending on particle size and charge. The collision results into kinematic coagulation.
4.	Gravitational agglomeration	While settling of particles with different sizes in a mixture (due to gravitational force) smaller particles collide with larger particles resulting into agglomeration. It is mainly size dependant process although shape of particles might decide the extent of agglomeration.
5.	Turbulent agglomeration	There are two types of mechanisms observed in this process- inertial agglomeration and shear agglomeration. The particles in turbulence usually follow a path line depending on size and/or velocity. While moving on the same path the particles may collide resulting in inertial agglomeration or collides with particle moving in different pathline resulting in shear agglomeration.

Low-Medium Pressure Pressed Agglomeration Process

Pressure agglomeration is contrast to growth agglomeration where external forces are applied. The agglomeration pressure forces act on continued mass of particulate solids which then densified. The mechanism of pressure agglomeration is illustrated in Figure. 1. There are three stages of pressure agglomeration process- as pressure increases densification of particles begins followed by elastic phase which causes weakening and cracking of particles and may sometimes cause destruction of agglomerated products. Thus in plastic phase maximum pressure is maintained for sometime called as dwell time prior to release to maintain the agglomerated particles.

Pressure agglomeration process can be performed by employing low, medium and high pressure equipments. The low and medium pressure agglomeration produces agglomerates that are porous and in his process the particle size and shape doesn't change.

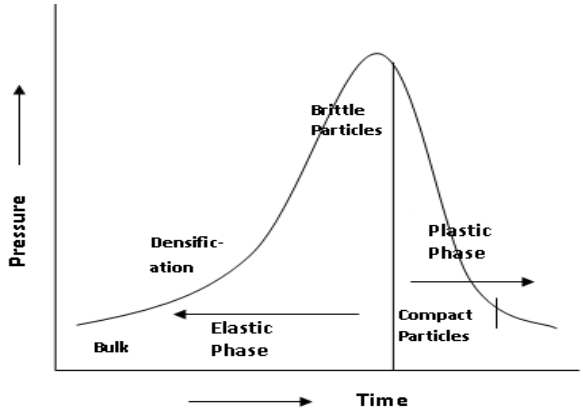

Figure 1: Mechanism of Low-Medium pressure agglomeration process

Agglomeration and shaping is due to pressure forcing the material through holes and as well as friction exerted by the material and the equipment. The low and medium pressure equipments are called as extruders (including screen and screw). The high pressure agglomeration is performed in presses such as punch and die press, compaction roller and the briquetting roller press.

1. Low-Medium Pressure Extruders

Extrusion is a compaction process of formation of agglomerates (extrudes) comprising of dry mixing of active with excipients, wet granulation of the mass, extrusion of wetted mass followed by drying and sizing of agglomerate mass.

Extrusion processes can be divided in wet extrusion[4], hot-melt extrusion[5] and cold extrusion[6]. In wet extrusion, some liquid binders are added to the powder, to facilitate the processing. After the extrusion process the obtained extrudes are dried, in order to form a rigid product. The presence of a solvent in wet extrusion processes entails two disadvantages, namely the possible degradation of moisture sensitive drug products and the additional drying step, which is time consuming.

Hot-melt extrusion is used in the pharmaceutical industry for the production of controlled release dosage forms[7]. In hot-melt extrusion, a high-melting polymer is added to the pharmaceutical substance. The extruder barrel is heated above the melting temperature of this polymer. The pharmaceutical drug particles get dispersed in the molten polymer, by rotation of the screw elements. The mixture solidifies when it leaves the extruder, through the die-plate.

In cold extrusion no liquids are added and the processing temperature stays low, which is good for temperature and water sensitive products. Cold extrusion is done with materials that yield under mechanical stress[8].

Extruders are available in variety of sizes, shapes and methods of operations. Extruders used for the extrusion have been classified as sieve and basket extruders, roll extruders, ram extruders and screw extruders.

Low pressure extrusion is the oldest method for the production of the granular material by agglomeration. Several years ago the granular products were yielded by pressing with hands the moist mass of the material through sieve (also called as sieve extruder). Later on the same process was mechanized and hands were replaced by the blade.

In recent another design modification was made where moist material mass is gravity fed in the basket having screen walls. Te vertical walls of the basket make up the extrusion screen. In this method the material falls into the chamber in front of extrusion blades as result it gets compressed in the nip between the rotating blades and the cylinders and forced through the screen openings forming the extrudes. Extrudes break off naturally or cut off by knife. Basket type of extrudes uses no or very low pressure and thus is useful for easy extruding materials. Extrudes obtained from this method are highly porous.

In order to achieve densification, additional compression force must act on the feed material. This can be achieved by using heavy rollers or pressurized rollers. The roller extruders are made up of two wheels or cylinders rotating in contra direction of which one or both can be perforated.

Ram extruder is widely used in the food industry to make snack vermicelli or similar products. It consists of piston that pushes the mass through the screen situated at the end of the barrel.

In recent times the most widely used extruders in the industry are screw extruders. This extruder uses screws to progress the material mass (wet/dry) along the barrel of the machine. There are two types of screw extruders- single screw extruder and twin- screw extruder.

2. Screw Extruders

The screw extruder machine consists of Archimedean screw (one or two) fitted closely in a cylindrical barrel having just sufficient clearance to allow its rotation. The feed material is fed in at one end and extrudes emerges from the other side through die[9].

2.1 Screw Extruder Components

The screw extrusion machine design can vary depending on the applications however the barrel, screw and die are the common components in every screw extruder.

Barrel: It is the central component of the extruder where the screw is rotating. The walls of barrel may be either smooth or with grooves. The barrel is divided into three zones- the feeding zone, the kneading zone and the extruding zone. The barrel may contain a heating and/or cooling zone depending upon the application. The heating/cooling can be provided either using heaters or refrigerating coils or using jacketed system.

Screw: Screw is main component of the extruder. It is responsible for advancing through force the material once accepted at the extruder inlet towards the exit of the extruder i.e. the die. The detailed design of an extruder screw is extremely complex and hence the features that will assist in understanding the process are discussed in this review (Table 2).

Table 2: Nomenclature of basic screw elements

Terminology	Definition
Flight	Conveying surface or thread
Pitch	Distance between two matching points of the flights on screw
Screw clearance	Distance between the barrel and the screw
Root	Flight of the screw is wound around the root and its diameter can vary.
Channel	Space between the flights in which material moves down the barrel

The screw of an extruder has flights (1 or 20) spiraling along the screw length. The extruder screw sometimes does not have the constant dimensions along the length of the screw. However, the diameter to the outside of the flight is constant along the length to allow close fit in the barrel. But as the roof diameter varies, the channel depth will vary as shown in Figure 2. The flight depth generally

decreases from feed end to die end. The ratio of the depth of the feed section flights to the metering section flights is called as screw compression ratio. The ratio may vary from 2:1 to 4:1. The pitch diameter of screw, the number of flights and the clearance between the flights and the barrel can each be adjusted to change the performance of the extruder. High speed and shallow flights create high pressures and on the contrary deep flights and low speeds create low pressure. A very low pressure extruder may feature screws with regularly placed flights and a straight shaft. This type of screw will provide some compression but the main function of such screw is to advance the material to the extrusion zone. Sometimes a space is left between the end of the screw and the die plate. This gap can help in producing dense extrude products if the rheological property of the material permits. Another important specification is the barrel L/D ratio (barrel length: barrel diameter) (Figure. 7). In recent advanced technology the L/D ratio has increased that means longer screw and hence higher friction.

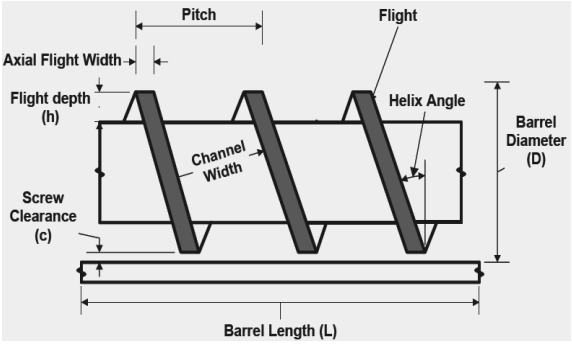

Figure 2: Geometry of screw in extruder

Die: The die of extruder is openings of different diameter and with different numbers depending on the product and is placed at the end of the screw. Based on construction of die the screw extruder can be axial type or radial type. In the axial type of screw extruders, the die opening (called as screen) is placed perpendicular with the axis of the screw (Figure. 3). The axial die extruders, it is difficult to cut extrudes into uniform lights as extrudes move faster on the outside and slower at the centre of the screen.

In radial screw extruder the die screens is placed around the screw. A third type called as dome extruder is also available which is hybrid between the axial and radial extruders.

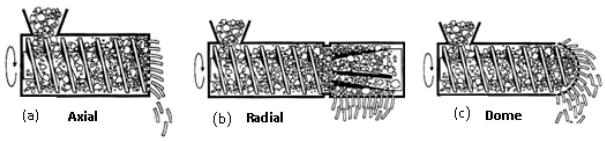

Figure 3: Diagram showing different types of Die openings

Power Transmission Equipment: The feed screw is the moving part and it must be driven. Operation in a steady and predictable manner is vital to making quality extrusions. Good speed control is extremely important to assure that adequate material is being fed to the process. However the ability to maintain even pressures to get consistent flow is equally important. Historically, DC drives and motors have been the ideal drives for extrusion. In recent past on the technology front, AC drives/motors are coming into their own as good extruder candidates.

2.2. Types of Screw Extruder

Screw extruders can be of single, twin or multiple screws (Rauwendaal, C. 1994. Polymer extrusion, Hanser, Munchen, Germany) rotating within a stationary barrel (Figure. 4).

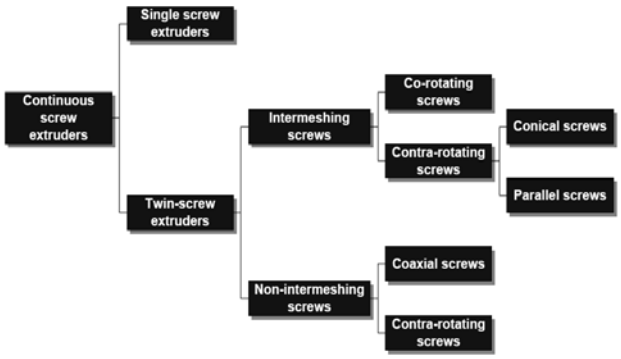

Figure 4: Schematic diagram presenting types of screw extruders

Single screw extruder: The single screw extruder is a machine designed with one screw to move the material through the barrel (Photo-1). Photo1 is an extruder machine manufactured by M/S Ankit Machines Pvt Ltd, Nashik (MS, India). The force in the single screw extruder is the friction of the material against the barrel wall that keeps the material from rotating with the screw and hence makes it advance towards the die/screen. Hence the transport is dependent upon the frictional and viscous forces associated with the mass. The single screw extruders are generally used for simple extrusion using prepared mixes or materials.

Photo 1: Single screw extruder machine; courtesy Ankit Machines Pvt Ltd, Nashik, (MS, India).

Twin screw extruder: Twin screw extruders are available in wide variety[10] of formats depending on the product and market needs (Figure. 5). These are characterized according to the screw configuration. The two main types of screw machines are – Counter-Rotating (rotating in opposite direction) or Co-Rotating (rotating in same direction). The two types are further subdivided based on the screw position- intermeshing or non intermeshing.

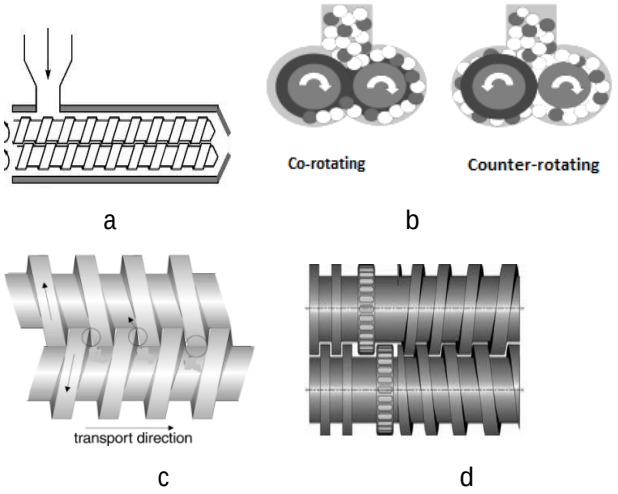

Figure 5: (a) Twin screw extruder; (b) co-rotating or counter- rotating screws; (c) intermeshing twin screws; (d) non- intermeshing twin screw

The non-intermeshing twin screw extruder consists of two single screw extruders fitted side by side with common barrel port. Just like single screw extruder this type of extruder depend on the friction for extrusion i.e. is mixing is not positive.

In intermeshing twin screw extruders, the screw partially overlap each other in a figure of '8' barrel track and forms small gaps which minimizes the leakage flow between the channels, thus, reducing mixing and residence time distribution. Beyond the direction of rotation or degree of intermeshing, screws can have various flight geometry and channel depth that can affect the operating characteristics and low viscosity slurries. Twin screw extruder handles oily or other material that slips in single screw extruder. These are also highly useful for thermo sensitive materials.

2.3. Process of Screw Extrusion

In the extrusion process two types of mixing mechanisms are observed- distributive mixing and dispersive mixing[11]. As the name indicates the distributive mixing is simply rearrangement of the particles in the extruder. This type of mixing does not alter the morphological properties of the material. In contrast in the high pressure region of the screw the dispersive mixing may cause particle size reduction of the material. The mixing in the extruder depends on the type of elements present in the screw.

The screw shaft is made of series of elements. These elements have particular functions to perform such as conveying, kneading, mixing etc. In order to alter the forces acting on the material the type of individual elements can be varied. These elements are classified as- mixing elements (and kneading elements), and conveying elements and mixing, forward and reverse conveying elements.

The conveying elements allow movement of material through the extruder. The conveying element consists of two parts viz. the number of flights and the pitch. The pitch is the axial length of one complete thread. Hence its length decides the conveying effect. More the pitch length faster the conveying effect and vice versa for smaller pitch lengths (Figure 6).

Kneading elements are used for the mixing of the material. Basically it consists of discs of certain thickness. These discs can serve multipurpose as can convey the material forward or cause dispersive or distributive mixing and for draining the material outside. Depending on the thickness of disc the mixing of material would be achieved. The thicker the disc dispersive mixing occurs and thinner disc would provide distributive mixing effect.

Mixing elements cause better homogenization of material affecting minimum shear. These are similar to the conveying elements with the difference that there are gap in the flights.

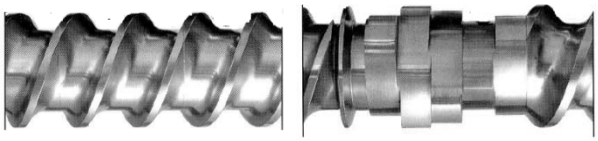

Figure 6: Elements of screw

Backward-pumping elements as the name indicates transport the product upstream instead of downstream. Hence cause distributive mixing or longitudinal homogenization.

The process of screw extrusion is sectioned into four zones i.e. the Feed zone, the Compression zone, the Metering zone and the Die zone (Figure. 7). The dry and wet materials are fed into the extruder into particulate moist solids or dough of varying viscosity. This first zone is usually termed as Feed zone and its function is to convey the material to subsequent zones. The screw depth in this zone is constant and the length of this zone is such as to ensure correct rate of feed advancement. The second zone is called as compression zone which has decreasing channel depth. In this zone the densification of material occurs firstly by the entrapped air.

The large screw angles helps in forwarding the movement of material. In the Metering section, pressurization of material occurs due to flow restriction and die at the other end (back pressure). Mixing or homogenization of material mainly occurs in the intermeshing section between the screws. The friction between the screw surface and the materials results in the generation of heat. In Hot Melt Extrusion Technique external heating sources are required to provide additional heating.

Additional heating can be achieved using a steam jacketed barrel and/or by a steam heated screw. In some applications the jacket is also used to cool the product using cold[12].

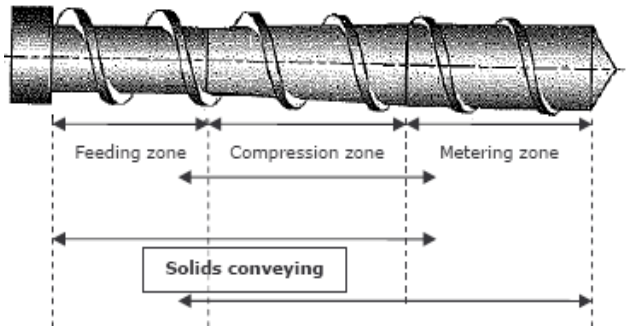

Figure 7: Schematic diagram showing the extrusion screw zones

Extrusion process variables: The quality of extrudes is affected by extrusion process variables. The extrusion process variables are termed as controlled variables that include screw speed, feed rate, steam water addition and barrel temperature (Table 3). The design variables can also affect the quality of extrudes and includes screw configuration, die size and shape, barrel length and diameter (L/D ratio).

Table 3: Process variables in relation to the extruder performance

Variable	Factors to be Monitored
System	➢ Temperature profile ➢ Pressure at the die ➢ Torque ➢ Degree of fill
Process	➢ Temperature ➢ Feed rate ➢ Screw Speed ➢ Water/ Steam addition ➢ Cutter speed
Design	➢ Screw configuration ➢ Die size/ shape ➢ Barrel (L/D)
Target	➢ Texture ➢ Color ➢ Flavor ➢ Nutritional value

Energy inputs: There are two types of energy input in screw extruder- motor power (torque) dissipation through shear and specific mechanical energy (SME) generated between the screw elements and the products. Torque is required to rotate the screw (effectiveness) i.e. it is the shaft or motor torque. By measuring the motor torque one can understand the resistance of material to the process and the conditions. It can be affected by the factors such as screw speed, moisture content and viscosity for feed, screw configuration and barrel temperature. SME is the energy provided by the motor device to the material in the extruder per unit mass (J/Kg). SME is generally correlated to extrude expansion i.e. the effect of material rheological properties. The screw configuration and screw speed affect the SME. The screw with more kneading and reverse elements increases SME.

Die Pressure: The pressure at the die determines the type of extrudes output. For extrusion, stress or pressure is required to overcome the resistance of the die (i.e. small holes of the die). One of the methods to determine die pressure is by mounting a strain gauge load cell mounted tangentially. The change in die pressure results directly on the dimensions of extrude. In another method viscosity measurement of the feed material can be correlated to die pressure. Reduced expansion of extrudes is observed when the material is highly viscous and the die pressure is low. Conversely, high die pressure on high viscosity material corresponds to highly expandable extrude.

Die Screen Openings: The die screen thickness and opening diameters sometimes affect the quality of extrude as the pressure on the die is altered. The thin die screen forms a rough and less dense extrudes whereas the high thickness die screen forms smoother and dense extrudes. The diameter of die screen openings determines the thickness of extrudes and the larger extrudes with more hardness are formed with larger die screen openings.

Physical and chemical modifications of extruded material: The material mass while flowing through the extruder and existing from die may undergo physical changes. The physical changes expected are- reorientation of molecules (this is due to high shear); melt or dough like material can be obtained (if exposed to high temperature, high pressure and high shear); as the extrudes exit from die expansion of extrudes occur resulting into high degree of porosity (this may be due to sudden release of pressure). If the material mass contains starch the complete gelatinization or partial gelatinization may occur depending on the pressure of heat and/or water.

CONCLUSION

The systematic study of low- medium pressure agglomeration extrusion process using extrusion technology has become need of the hour. A link is required between the basic engineering aspects of extrusion processing and the physicochemical changes occurring in agglomerated products in order to solve the problems associated with extrusion process. The low-medium pressure pressed agglomeration process warrant good future due to economy of the process.

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