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A METHOD AND A SYSTEM FOR PROCESSING WASTE MINERAL MATERIAL

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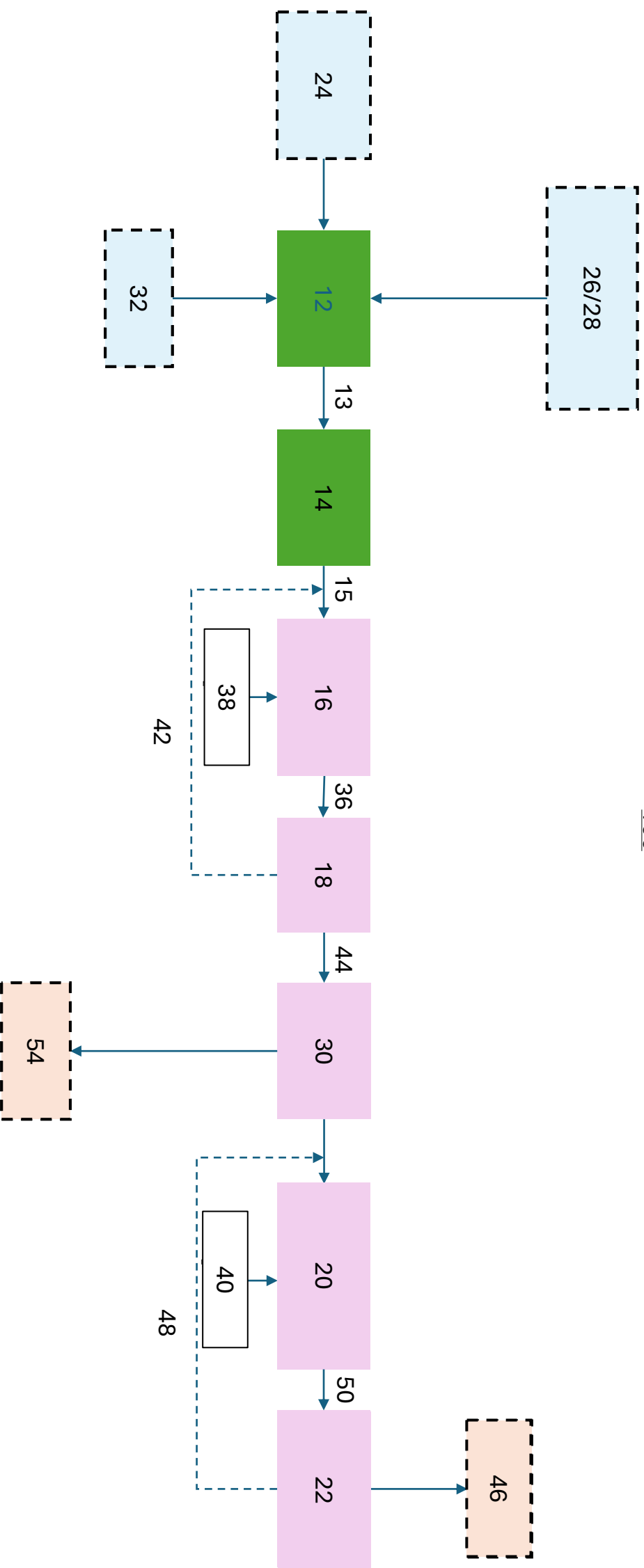
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ABSTRACT

Disclosed is a method of upgrading a feed bauxite waste material. The method includes drying the feed bauxite waste material to form a dried material. Then, the method includes comminuting the dried material to form a ground material. The ground material is then subjected to mechano-chemical activation to form an activated material. The feed bauxite waste material may comprise either or both bauxite residue and bauxite tailings. The method may include subjecting the ground or activated material to a magnetic separation step to remove ferromagnetic material.

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A METHOD AND A SYSTEM FOR PROCESSING WASTE MINERAL MATERIAL

Field of invention

The present invention relates to a method and system for processing waste mineral material including aluminium-containing material generated by an industrial process.

The present invention relates particularly, although by no means exclusively, to a method and system for upgrading waste mineral material from the Bayer process and/or bauxite beneficiation process.

The present invention relates particularly, although by no means exclusively, to a method and system for processing waste mineral material from the Bayer process and/or the bauxite beneficiation process into a supplementary cementitious material (SCM).

Background

The Bayer process is used for the manufacture of alumina from bauxite ore in the production of aluminium.

In essence, the Bayer process involves using concentrated caustic solution to form sodium aluminate, separating the resultant slurry into solids and liquor streams, precipitating aluminium tri-hydrate from the liquor and calcining the aluminium tri-hydrate to form alumina. The basic steps of the Bayer process are as follows.

1. Comminution: Incoming bauxite is ground and mixed with caustic liquor to form a slurry.
2. Digestion: The slurry is sent to a digestion step where the slurry is heated to between ~140°C and 260°C depending on the type of bauxite.
3. Flash down: The heated slurry is cooled by steam evaporation or flashing in a cascade of vessels.
4. Clarification: The solid and liquid components of the slurry are separated using a cascade of settlers or deep cone separators and the entrained liquor is recovered. The solids component (also known as bauxite residue or red mud) is sent to a permanent disposal/storage site. The liquid component, which is in the form of pregnant liquor and washings, is sent to filtration to remove any residual solids.
5. Precipitation: The filtered liquid component is gradually cooled to allow the dissolved alumina to precipitate as alumina tri-hydrate ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$).
6. Calcination: The alumina tri-hydrate ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) is calcined at ~1,000°C to form alumina, typically >99.5% Al_2O_3 .
7. Evaporation: The spent liquor from the precipitation step is heated and subsequently cooled. The condensate is re-used in the process, for example as boiler feed water or for

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5 washing the bauxite residue. The remaining spent liquor is washed and recycled back to the digestion step.

To improve the efficiency of the Bayer process, mined bauxite ore is typically beneficiated to separate target aluminium minerals, enriching the aluminium concentrate and removing impurities (such as silica, iron, titanium and other minor minerals) that could create further issues during the refining process before the beneficiated ore is used as feedstock in the Bayer process. The removed impurities form bauxite tailings.

With the mining industry focusing on developing more efficient and environmentally sustainable technologies, the Applicant has invested significant resources in improving their existing mineral extraction and recovery processes.

15 With respect to aluminium production, the Applicant has conducted research into recovering value from waste material from a Bayer process refinery and/or bauxite beneficiation plant, particularly residue generated during the Bayer process and tailings generated during bauxite beneficiation.

20 Bauxite residue is particularly problematic. A large volume of highly alkaline bauxite residue is typically formed and discharged from the Bayer process refinery at the end of the process. For every tonne of alumina, 1-1.5 tonnes of bauxite residue are usually formed.

The residue is usually stored in a residue disposal storage facility in the form of a lagoon or stacked as dry mud and has to be carefully managed because its high alkalinity poses a health and environmental hazard if the residue leaches into the environment particularly into the ground water.

25 Traditionally, only a small proportion of bauxite residue produced is re-used because of the challenges posed by its high pH and complex oxides mixture and minerology. As a result, the residue disposal storage facility can contribute to a significant portion of a Bayer process refinery footprint. Similarly, tailings generated from the bauxite beneficiation process is stored in a waste disposal storage facility that can contribute to a significant portion of a bauxite beneficiation plant.

30 It follows that it would be desirable to provide a method and system for extracting value from bauxite residue and/or tailings.

It is also desirable to provide a method and a system for processing bauxite residue and/or tailings into a useful product with a reduced energy consumption or powered at least in part by a renewable energy source.

35 **Summary of the invention**

The present invention relates to a method and system for upgrading waste mineral material from an industrial process. One suitable example is bauxite waste material including aluminium-containing material, suitably sourced from the Bayer process or the bauxite beneficiation process.

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5 A motivation for the development of the present invention is the desire to process bauxite waste material in an environmentally sustainable manner.

10 In this specification, the term “bauxite waste material” encompasses waste mineral material generated by a Bayer process refinery including residue generated during the Bayer process and tailings generated during bauxite beneficiation, individually or in combination, that is typically disposed or stockpiled because of an inability to extract value from the waste material using existing technologies. It can be appreciated that the bauxite beneficiation plant and Bayer process refinery may be located remotely from each other or be co-located on the same site.

15 In this specification, the term “mineral material” encompasses any naturally occurring inorganic substance.

In this specification, the term “upgrading” refers to a process of producing a higher value or purified product from bauxite waste material.

In this specification, the term “substantial” refers to a quantity greater than 50 wt%.

20 The upgraded bauxite waste material may either be in a form that can be repurposed for another application or in a form that can be further processed in a more efficient manner. For example, upgrading bauxite residue and/or bauxite tailings may provide a supplementary cementitious material (SCM) for the building industry and iron-rich streams for further processing in the steel industry.

In this respect, bauxite residue and bauxite tailings often contain reactive components particularly silicon-containing materials such as kaolinite and alumina silicates.

25 The present invention was developed at least in part to manipulate these components to allow the bauxite waste material to be converted into a form that can be repurposed for another application.

The present invention provides a method of upgrading a feed bauxite waste material, the method including:

(i) drying the feed bauxite waste material to form a dried material;

(ii) comminuting the dried material to form a ground material; and

30 (iii) subjecting the ground material to mechano-chemical activation to form an activated material.

35 During mechano-chemical activation, energy is applied to the bauxite waste material via mechanical instead of thermal means (i.e. by heating) to increase the reactivity of at least one component in the bauxite waste material. During this step, the bauxite waste material initially undergoes a conventional comminution (e.g. grinding/milling) step in which the particle size is reduced to increase its particle size to surface area ratio. Prolonged comminution of the bauxite waste material imparts energy to the material beyond that minimum particle size which causes the material to aggregate and agglomerate into an upgraded activated material such as a binding agent, particularly as a supplementary cementitious material (SCM). It is contemplated that mechano-

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chemical activation may be favourable over thermal activation means for processing waste mineral material as it may be less energy intensive and/or may be partially or fully electrically powered, allowing for the possibility for the process to be powered by renewable energy sources.

The bauxite waste material may substantially comprise bauxite residue. It will nevertheless be appreciated that a feedstock for the method disclosed herein may be a mixture of the bauxite waste material and other materials such as but not limited clay, concrete, fly ash, cement clinker, slag and silicates. Beneficially, the re-purposing of the bauxite residue into an SCM may generate an additional revenue stream from waste material while reducing the amount of waste material generated in Bayer process refineries and bauxite beneficiation plants and consequently reduce the footprint of the waste disposal facilities in these facilities.

The feed bauxite waste material may be subjected to a comminution step to form a feed material having a maximum average particle size of 2 mm, suitably 1 mm, more suitably 0.5 mm, even more suitably 250 μm .

The method may include mixing the feed bauxite waste material with an additive.

The additive may be used to increase reactivity of the formed bauxite waste material mixture. One suitable example of such an additive is kaolinitic clay. Suitably, the kaolinitic clay has a maximum average particle size of 10 mm, suitably 5 mm, more suitably 2 mm.

The additive may comprise a reducing agent. The reducing agent may be used to convert at least one component of the bauxite waste material into a ferromagnetic material, suitably by reducing hematite into magnetite. Suitable reducing agents include carbon (including biochar), metallic Fe, Al, Zn, Mg, Ca, iron (II) sulfate (FeSC), and iron (II) sulfate monohydrate ($\text{FeSC} \cdot \text{H}_2\text{O}$).

The mixing step may include forming a bauxite waste material mixture comprising up to 90wt% bauxite waste material, suitably up to 80wt% mineral material, more suitably ranging from 65-80wt% bauxite waste material.

The mixing step may include adding the additive up to 35 wt%, suitably up to 30 wt%, more suitably up to 20 wt%, even more suitably up to 10 wt% of the bauxite waste material mixture.

The mixing step may include adding kaolinitic clay to the bauxite waste material.

The mixing step may include adding bauxite tailings to the bauxite waste material. Suitably, the bauxite tailings have a maximum average particle size of 2 mm, suitably 1 mm, more suitably, 0.5 mm, even more suitably 250 μm .

The drying step may involve drying the bauxite waste material to less than 10 wt% water content, suitably less than 5 wt% water content, more suitably less than 2 wt% water content, even more suitably less than 1 wt% water content.

Reducing the water content of the bauxite waste material may help preserve the reactivity of the bauxite waste material. Providing a dry material may also enable dry magnetic separation.

5 The comminution step may involve grinding the dried material in the absence of a fluid. In this embodiment, the dried material is subjected to dry grinding as opposed to wet grinding. Suitably, the comminution step involves grinding the dried material in an environment having less than 10 wt% moisture content, suitably less than 5 wt% moisture content, more suitably less than 2 wt% moisture content, even more suitably less than 1 wt% moisture content.

10 The comminution step may involve grinding the dried material in a high energy mill. The high energy mill may be a planetary ball or dry agitator bead mill. Suitably, the comminution step includes forming a ground material having a maximum average particle size of 15 microns, suitably up to 10 microns, more suitably less than 5 microns.

15 The comminution step may be performed in the presence of a gas. Suitably, the method includes supplying a gas for the comminution step.

The gas may comprise less than 5 wt% oxygen, more suitably less than 3 wt% oxygen, even more suitably less than 1 wt% oxygen. More suitably, the gas comprises at least 50 wt% nitrogen and less than 1 wt% oxygen.

20 The method may include separating the ground material into a ground coarse fraction and a ground fines fraction. Suitably, the method includes recycling the ground coarse fraction back to the comminution step. This enables the ground coarse fraction to be processed to a particle size suitable for mechano-chemical activation.

25 The ground material separating step may include directing the ground material into a classifier to separate the ground coarse and the ground fines fractions. Suitably, the ground material separating step includes classifying the ground material such that the ground coarse fraction size is not greater than twice the lowest ground fines fraction size. Typically, comminuting the bauxite waste material forms a non-homogeneous mixture. Recirculating the coarser fractions back to the comminution step enable these fractions to be reprocessed to increase the proportion of ground fines fraction and provide a final output having a more homogeneous particle size distribution.

30 The method may include a magnetic separation step to remove ferromagnetic material, suitably iron oxide, more suitably magnetite.

The method may include subjecting the ground material to a magnetic separation step.

The method may include subjecting the activated material to a magnetic separation step.

35 The method may include analysing the ground material and/or the activated material using one or more methods selected from a group comprising IR spectroscopy, RAMAN spectroscopy, X-ray diffraction analysis, LIBS, heat flow calorimetry, thermogravimetry, scanning electron microscopy, particle size and/or particle shape analysis, NMR spectroscopy to characterise the material before and after the magnetic separation step.

5 Comminution of the dried material and mechano-chemical activation of the ground material may be performed in a single step. Alternatively, the method comprises separate comminution and mechano-chemical activation steps.

Mechano-chemical activation may increase the reactivity of the ground material to enable the formed activated material to be used as a supplementary cementitious material.

10 Mechano-chemical activation may increase the R^3 value of the bauxite waste material. Suitably, mechano-chemical activation provides bauxite waste material having a minimum R^3 value of 250 J/g SCM, more suitably 300 J/g SCM, even more suitably above 350 J/g SCM.

15 Mechano-chemical activation may involve processing the ground material or the iron/magnetite-depleted product from the magnetic separation step in a high energy mill. The high energy mill may be a planetary ball or dry agitator bead mill. Suitably, mechano-chemical activation involves subjecting ground material to an energy input of at least 100 kW/m³, suitably at least 150 kW/m³, more suitably at least 200 kW/m³.

20 Mechano-chemical activation may include processing the ground material in a high energy mill operating at a circumferential speed of up to 10 m/s, suitably up to 5 m/s, more suitably ranging from 3-5 m/s.

Mechano-chemical activation may include aggregating and agglomerating the ground material to form the activated material. Suitably, the mechano-chemical activation is performed until agglomeration of the ground material occurs.

25 Agglomeration is typically used to confirm activation of the bauxite waste material. Suitably, the mechano-chemical activation step includes detecting agglomeration of the ground material and stopping the activation step once optimal agglomeration of the ground material is achieved. Optimal agglomeration may be based on a predetermined average particle size of the agglomerates. A suitable average particle size of the agglomerates may be less than 60µm or preferably less than 50µm.

30 The mechano-chemical activation may be performed in the presence of a gas. Suitably, the method includes supplying a gas for the mechano-chemical activation.

The gas may comprise less than 5 wt% oxygen, more suitably less than 3 wt% oxygen, even more suitably less than 1 wt% oxygen. More suitably, the gas comprises at least 50 wt% nitrogen and less than 1 wt% oxygen.

35 The method may include separating the activated material into an activated coarse fraction and an activated fines fraction. Suitably, the method includes returning the activated fines fraction to the comminution step.

The activated material separating step may include directing the activated material into a classifier to separate the activated coarse fraction from the activated fines fraction. Suitably, the

5 activated material separating step includes classifying the activated material such that the activated coarse fraction size is not greater than twice the lowest activated fines fraction size.

The activated material separating step may include recycling the fines fraction to the mechano-chemical activation step.

10 The method may include isolating and recovering the activated coarse fraction. The bauxite waste material may be processed for use in the building industry, suitably as a supplementary cementitious material. Suitably, the method includes processing the activated coarse fraction into SCM.

The present invention also provides a system for performing the previously described method.

15 The present invention also provides a system for upgrading a feed bauxite waste material, the system comprising:

(a) a dryer configured to dry the feed bauxite waste material to form a dried material; and

(b) at least one mill configured to comminute the dried material to form a ground material and subjecting the ground material to mechano-chemical activation to form an activated material.

The system may form part of a bauxite beneficiation plant and/or Bayer process refinery.

20 The system may include a comminutor to form feed bauxite waste material having a maximum average particle size of 2 mm, suitably 1 mm, more suitably, 0.5 mm, even more suitably 250 μm . Suitably, the comminutor is a grinding mill or crusher.

The system may include a comminutor to comminute any additives to a maximum average particle size of 2 mm, suitably 250 μm . Suitably, the comminutor is a grinding mill or a crusher.

25 The system may include a mixer configured to mix the bauxite waste material with an additive to form a mixture. The additive may be a reactivity-increasing additive or a reducing agent as previously described.

The system may include a ground material classifier configured to separate the ground material into a ground coarse fraction and a ground fines fraction.

30 The system may include an activated material classifier configured to separate the activated material into a coarse activated fraction and a fines activated fraction.

The ground material classifier and activated material classifier may be selected from an air classifier, jet classifier, centrifuge, cyclone separator, or a vibratory or rotary screen.

35 The ground material classifier may include a recycle loop configured to return the ground coarse fraction to the at least one mill.

The second classifier may include a recycle loop configured to return the activated fines fraction to the at least one mill.

5 The system may include a first mill configured to comminute the dried material to form the ground material and a second mill configured to subject the ground material to mechano-chemical activation to form the activated material.

10 The system may include a combined mill configured to comminute the dried material to form the ground material and subject the ground material to mechano-chemical activation to form the activated material.

The at least one mill may be a high energy mill. The high energy mill may be planetary ball or dry agitator bead mills.

The system may include a compressor to deliver a gas into the at least one mill.

15 The system may include a magnetic separator configured to remove ferromagnetic material, suitably iron oxide, more suitably magnetite.

The magnetic separator may be configured to receive and process the ground material to remove ferromagnetic material.

The magnetic separator may be configured to receive and process the activated material to remove ferromagnetic material.

20 The magnetic separator may be located between the first and second mills, or downstream of the second mill.

The magnetic separator may be located after the combined mill.

25 The system may include an analyser for analysing the ground material and/or the activated material to characterise the material entering and/or exiting the magnetic separator. The analyser may be configured to perform one or more methods selected from IR spectroscopy, RAMAN spectroscopy, X-ray diffraction analysis, LIBS, heat flow calorimetry, thermogravimetry, scanning electron microscopy, particle size and/or particle shape analysis, NMR spectroscopy.

The system may include a controller for classifying the ground material such that the ground coarse fraction size is not greater than twice the lowest ground fines fraction size.

30 The system may include a controller for classifying the activated material such that the activated coarse fraction size is not greater than twice the lowest activated fines fraction size.

The system may include a compressor to deliver a gas into at least one of the mills.

The system may include an SCM recovery unit to process the activated coarse fraction into SCM.

35 **Brief Description Of Drawings**

Various embodiments of the invention are hereinafter described by way of example only with reference to the accompanying drawings, wherein:

Figure 1 illustrates Flowsheet Option 1 for processing a bauxite waste material according to one form of the present invention.

Figure 2 illustrates Flowsheet Option 2 for processing a bauxite waste material according to another form of the present invention.

Figure 3 illustrates Flowsheet Option 3 for processing a bauxite waste material according to another form of the present invention.

Figure 4 illustrates Flowsheet Option 4 for processing a bauxite waste material according to another form of the present invention.

Figure 5 illustrates Flowsheet Option 5 for processing a bauxite waste material according to another form of the present invention.

Figure 6 provides a table summarising examples of compositions of blended feedstocks that may be processed by the system of Figures 1-5.

Detailed Description

A system as according to an embodiment of the present invention is marked as 100 in Figure 1 (Flowsheet Option 1). The system is configured to process feed bauxite waste material comprising substantially bauxite residue, in this example, 80 wt% bauxite residue and 20 wt% kaolin (also known as kaolinitic clay) to form supplementary cementitious material (SCM) for producing concrete. It will be appreciated that in other examples the system may process feedstock comprising other substantial proportions of bauxite residue, e.g. more than 50%, or preferably in the range 65-80 wt% bauxite residue and 20-35 wt% additive such as kaolin.

The system comprises (a) a mixer 12 to mix a bauxite waste material with an additive to form a mixture, (b) a dryer 14 to dry the mixture, (c) a first mill 16 to dry grind the dried mixture to form a ground mixture, (d) a first classifier 18 to separate the ground mixture into a ground coarse fraction and a ground fines fraction, (e) a second mill 20 to activate the fines fraction and form an activated mixture and (f) a second classifier 22 to separate the activated mixture into a coarse activated fraction and an activated fines fraction.

The high energy mills 16 and 20 and classifiers 18 and 22 comminute and screen a blended feedstock 13 comprising bauxite residue 24 and reactive material-containing additive in the form of kaolinitic clay 26 to meet the average particle size requirements of the process.

A reducing agent 32 is added to convert hematite in the blended feedstock 13 into magnetite (comprising Al, Zn, Mg, C, Ca, iron (II) sulfate, iron (II) sulfate monohydrate). This enables the recovery of magnetite as a separate product stream, if desired, using magnetic separator 30.

The system includes suitable storage tanks for storing and delivering the reducing agent and the kaolinitic clay into the mixing tank.

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5 The dryer 14 is configured to reduce the water content of the blended feedstock 13 to less than 1 wt%. The drying process is controlled to ensure that the chemical or physical properties of the blended feedstock 13 remains unaltered.

10 The first high energy mill 16 in the form of a planetary ball or dry agitator bead mill receives and dry grinds the dried mixture from the dryer 14 to form a ground mixture having a maximum average particle size of 10 microns, suitably 5 microns. In some embodiments, the first mill 16 has a length-to-diameter ratio of 2.5 to 5 and is connected to a gas line 38 to deliver a nitrogen-rich gas with less than 1 wt% O₂ to ensure that the grinding process is performed in a low oxygen and moisture environment.

15 The first high energy mill 16 is connected to a first classifier 18 in the form of an air classifier to separate the ground mixture into a coarse fraction 42 and a ground fines fraction 44. A recycle loop connects the first classifier 18 with the first high energy mill 16 to return the coarse fraction 42 for further grinding.

20 To recover ferromagnetic material 54 such as magnetite, a magnetic separator 30 is located immediately downstream of the first classifier 18 to remove magnetite from the ground fines fraction 44 as a waste or product stream (depending on the commercial value of the stream to the Applicant). This step is performed before the magnetite-depleted ground fines fraction is fed into a second high energy mill 20 and subjected to mechano-chemical activation to activate the magnetite-depleted fines fraction and form activated agglomerates 50.

25 The mechano-chemical activation of the bauxite waste material comprises the following three phases:

Stage 1: Mechanical reduction of bauxite waste material. This stage involves comminution, for example by crushing and grinding, of the bauxite waste material in the Rittinger Zone to form a particle mixture that has an average particle size that does not reduce with further comminution.

30 Stage 2: Activation of particle mixture from stage 1. This stage involves the processing of the particle mixture in a high energy mill to change the particle crystallographic structure by breaking atomic bonds, and replacing individual atoms or entire groups of atoms in the structure.

Stage 3: Agglomeration of the particle mixture from stage 2. This stage involves further processing of the particle mixture in a high energy mill to agglomerate the particles in the mixture.

35 The activated mixture 50 is sent to the second classifier 22 which separates the agglomerates from the activated fines fraction 48. The separated agglomerates are processed into the final SCM product 46 while the activated fines fraction 48 exiting the second classifier is returned to the mill 20 for further processing into agglomerates and ultimately SCM.

Figures 2 to 5 illustrate further systems (Flowsheet Options 2-5) for processing bauxite waste material into SCM.

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Flowsheet Option 2 in Figure 2 comprises a system 200 configured to have operational units that are substantially identical to system 100 except that the magnetic separator 30 is located immediately downstream of the second classifier 22. This allows the magnetic separator to receive and treat a substantially homogenised activated mixture to remove ferromagnetic material 54 and produce a magnetite-depleted activated coarse fraction that is processed into the final SCM product 46.

A reducing agent 32 is added to the mixer 12 to convert hematite in the feedstock to magnetite for removal by the magnetic separator 30.

The second high energy mill 20 is in the form of a planetary ball or dry agitator bead mill having a length-to-diameter ratio of 2.5 to 5 which is filled 50-70 vol% of grinding media having an average particle size of 3-6 mm.

Similar to the first high energy mill 16, the second high energy mill 20 is also connected to a gas line 40 to provide a low moisture environment for the activation step.

The second high energy mill 20 is also directly connected downstream to a second classifier 22 in the form of an air classifier to form an activated coarse fraction that is processed into the final SCM product 46, and an activated fines fraction 48. A recycle loop connects the second classifier 22 with the second high energy mill 20 to return the activated fines fraction 48 for further treatment so that a substantially homogenised activated mixture can be formed for processing into the final SCM product 46.

In some embodiments, the first and second high energy mills 16, 20 and/or the first and second classifiers 18, 22 are controlled to ensure that the coarse fraction size is not higher than twice the lowest fines fraction size. Appropriate sensors may be incorporated into the mills or classifiers to measure the amount of coarse and fines fractions formed.

Flowsheet Option 3 in Figure 3 is not configured to recover ferromagnetic material from the feedstock 13. The configuration of the operational units in system 300 are substantially identical to system 200 except for the absence of the reducing agent 32 (to generate the ferromagnetic material from the feedstock) and the magnetic separator 30. In system 300, the ground fines fraction 44 is fed directly into the second high energy mill 20 and the activated coarse fraction exiting the second classifier 22 is processed into the final SCM product 46.

System 400 in Figure 4 is a variation of system 200 in which a combined high energy mill 120 is configured to perform the function of the first and second high energy mills 16 and 20 of system 200. The system 400 includes the same upstream operational units of system 200 comprising mixer 12 and dryer 14 that are configured to receive the same inputs as system 200. A single combined high energy mill 120 is located downstream of dryer 14 to grind and activate the dried feedstock 15 in system 400.

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5 A second classifier 22 is located downstream of the combined high energy mill 120 to separate the activated material into a substantially homogenised activated coarse fraction comprising agglomerates that is directed into magnetic separator 30, and an activated fines fraction 148 that can be returned to the combined high energy mill 120 via a recycle loop. As with system 200, the magnetic separator 30 receives and treats the activated agglomerates to remove ferromagnetic material 54 and form a magnetite-depleted activated coarse fraction that is processed into the final SCM product 46. A gas line 140 is provided to create a low moisture environment in the combined high energy mill 120 for the activation step.

10 System 500 of Figure 5 is a variation of system 300 in which a single high energy mill 120 is configured to perform the function of the first and second high energy mills 16 and 20 of system 300. System 500 includes the same upstream operational units of system 300 comprising mixer 12 and dryer 14 that are configured to receive the same inputs as system 300. A single combined high energy mill 120 is located downstream of dryer 14 to grind and activate the dried feedstock 15 in system 500.

15 A second classifier 22 is located downstream of the combined high energy mill 120 to separate the activated feedstock exiting the combined high energy mill 120 into a substantially homogenised activated coarse fraction that is processed into the final SCM product 46 and an activated fines fraction 148 that can be returned to the combined high energy mill 120 via a recycle loop. A gas line 140 is provided to create a low moisture environment in the combined high energy mill 120 for the activation step.

20 In one exemplary operation of a system according to the present invention, bauxite waste material in the form of bauxite residue is sourced from a Bayer process refinery. The bauxite residue can be obtained from operational and non-operational Bayer process refineries and suitably has a maximum average particle size of up to 2 mm.

25 In instances when the bauxite residue is assessed to contain insufficient reactive components (e.g. alumina silicate) to form the SCM, the feedstock is supplemented with a reactive material-containing additive such as kaolinitic clay 26 or bauxite tailings 28 to increase the reactivity of the bauxite waste material to a level that can allow the bauxite waste material to be activated.

30 Figure 6 provides examples of bauxite waste material feedstocks that may be processed by systems 100-500. BR1-BR3 represent different types of bauxite residue. BR2 and BR3 are obtained from the same source but with BR2 being neutralised by sea-water. The "Flowsheet Option" column in Figure 6 identifies the system 100-500 that may be suitable for processing the specific feedstock composition.

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5 It should be appreciated that whilst the detailed description identifies bauxite residue as the main feedstock, the systems of the present invention are equally adaptable for processing feedstocks substantially comprising bauxite tailings.

10 Bauxite tailings are typically obtained from a bauxite beneficiation process that is performed to increase the purity of bauxite ore feedstock for the Bayer process. The beneficiation process usually involves excavating, loading and transporting run-of-mine (ROM) bauxite ore by truck to a stockpile or hopper bin located at a beneficiation plant.

15 ROM material sourced directly from a mine and/or from a stockpile may be fed via a hopper into a feeder. The material from the feeder is crushed and mixed with process water to form a slurry for wet scrubbing in a single rotating drum type wet scrubber. The scrubbed component of the ROM is pumped to a tank where it is separated by a cyclone, classifier and dewatering screen. The beneficiated ore is then transferred by a conveyor to a storage beneficiated product bin or a stockpile. The scrubber sump, feeder sump and fines sump material are screened, and the solids are transferred to a rejects stockpile by a conveyor. Rejected material from the classifier and dewatering screen are sent to a recycle tank. The wet tailings from the cyclone and recycle tank are delivered to a tailings tank before being pumped to a tailings dam.

The waste bauxite material can be recovered to be processed by the present invention as the main feedstock or as an additive to increase the reactivity of the main feedstock.

25 In some examples, up to 35 wt% reactive material-containing additive can be added to the feedstock to meet the minimum reactive requirements. The additives may have a maximum average particle size of up to 2 mm for optimal energy consumption, particularly because larger particle sizes require more energy and time to achieve a substantially homogeneous output of fine particles.

30 The bauxite residue 24 is mixed with 20 wt% of kaolinitic clay 26 to form a blended feedstock 13. As shown in Figure 6, the purity of the kaolin content can range from 60-100%. It can be appreciated that if the bauxite residue feedstock 24 is assessed to contain sufficient reactive material, the addition of reactive material-containing additive is not required.

A reducing agent 32 is also added to the mixer 12 to convert any hematite present in the bauxite residue feedstock 24 into magnetite.

35 The blended feedstock 13 is then dried to a temperature ranging from 105-150 °C using dryer 14 to reduce the water content to less than 1 wt%. The dried blended feedstock 15 is then directed into the first high energy mill 16 to perform stage 1 of the mechano-chemical activation process. In this stage, the first mill 16 is operated using predetermined parameters to comminute the dried blended feedstock 15 until a substantially stable average particle size not exceeding 5 microns is reached (i.e. continued comminution of the dried blended feedstock 15 does not result in further reduction in particle size). The comminution step is performed in a low oxygen gaseous environment

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comprising at least 50 wt% nitrogen and less than 1 wt% oxygen that is provided by gas line 38. In some embodiments, nitrogen may be substituted with carbon dioxide.

The ground material 36 from the first high energy mill 16 is then separated into coarse fraction 42 and ground fines fraction 44 using a cyclone separator 18 in which the coarse fraction 42 is returned to the first high energy mill 16 to be further ground into material that gets classified as ground fines fraction 44.

A dry magnetic separator 30 is located between the first and second mills 16, 20 in system 100 to remove any magnetite formed in first mill 16. Flowsheet Options 2 and 4 illustrate alternative systems in which the dry magnetic separator 30 is located after the second mill 20 to receive classified material exiting second classifier 22. The location of the magnetic separator may depend on the anticipated amount of ferromagnetic material formed (e.g. conversion of hematite to magnetite). For example, the dry magnetic separator 30 may be located after the second classifier 22 if the formation of the ferromagnetic material in the first mill 16 is not expected to be sufficient to be recovered cost effectively.

If recovery of ferromagnetic material is not required, the ground fines fraction 44 is supplied directly into the second high energy mill 20 before being processed into the final SCM product 46 (see Flowsheet Option 3).

In system 100 (as well as systems 200 and 300), stages 2 and 3 of the mechano-chemical activation process are performed in the second high energy mill 20 which subjects the ground fines fraction 44 to an energy input of at least 200 kW/m³ and a circumferential speed ranging from 3-5 m/s.

During the initial processing period in the second high energy mill 20, the energy imparted to the ground fines fraction 44 and subsequent chemical reaction causes the crystal structure, bonds and oxidation states of atoms in the reactive components in the ground fines fraction 44 to change. The change is particularly pronounced on the particle surfaces and activates the ground fines fraction 44.

This defines stage 2 of the of the mechano-chemical activation process.

Subsequently, prolonged processing of the activated ground material in the second high energy mill 20 causes agglomeration of the activated ground material into a form that is suitable for use as a SCM.

The agglomerated mixture 50 is then classified into an activated coarse fraction and an activated fines fraction using a second classifier 22 in the form of a cyclone separator in which the activated coarse fraction is isolated and forms the final SCM product 46 while the activated fines fraction 48 is returned to the second high energy mill 20 to be reprocessed into agglomerates 50.

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5 The operating parameters for the first and second high energy mills 16, 20 and/or the first and second classifiers 18, 22 are adjusted to ensure that the coarse fraction size is not higher than twice the lowest fines fraction size.

10 The mechano-chemical activation process is conducted differently in systems 400 and 500 which utilised a combined high energy mill 120 instead of separate first and second high energy mills. During operation of system 400, the dried feedstock 15 exiting dryer 14 is fed into the combined high energy mill 120 located downstream of dryer 14. In the mill 120, all three stages of mechano-chemical activation are performed. This involves grinding the dried feedstock until a substantially stable average particle size not exceeding 5 microns is reached. Thereafter, the ground fines fraction 44 is further processed in the mill to impart an energy input of at least 200 kW/m³ to the ground fines fraction 44 until agglomeration occurs which indicates activation of the dried feedstock. The agglomerated mixture 50 is sent to the second classifier 22 which separates the agglomerates from the activated fines fraction 148. The separated agglomerates are then subjected to a magnetic separation step using magnetic separator 30 to isolate magnetite 54 before the magnetite-depleted agglomerates are processed into the final SCM product 46. The activated fines fraction 148 exiting the second classifier can be returned to the mill 120 for further processing into the agglomerates.

20 System 500 operates in a similar manner to system 400 except that a reducing agent is not added to the feedstock to reduce hematite into magnetite in the feed and consequently magnetic separation of the agglomerated mixture 50 is not performed.

25 For both systems 400 and 500, suitable milling speeds/parameters for (1) grinding and also for (2) activation are selected to allow the comminution and activation steps to be performed in a single mill, and suitably in a continuous milling step. For example, appropriate lengths of time taken to achieve (1) grinding (to a suitable degree) and (2) activation may be determined during testing by sampling the processed feedstock and/or utilising sensors to determine material properties. It may be more straightforward to determine the time required to achieve a particular particle size distribution in step (1) compared to activation. As a consequence, while it is possible for the grinding time in step (1) to be fairly consistent and therefore preset, the systems 400, 500 may be configured to continue step (2) until certain properties of the comminuted material are achieved (e.g. agglomeration) instead of performing step (2) for a preset time period. In this respect, step (2) may involve periodically sampling the comminuted material during the milling step to obtain mineralogy and calorimetry information (e.g. reactivity from hydration perspective and measuring energy in joules). A model may be developed to adjust the operating parameters to optimise activation and determine the activation treatment period. Sensors may be installed in the mill to provide feedback

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5 on real-time operating conditions to a control unit that adjusts parameters based on the optimisation model.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

10 In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

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Claims

1. A method of upgrading a feed bauxite waste material, the method including:
 - (i) drying the feed bauxite waste material to form a dried material;
 - (ii) comminuting the dried material to form a ground material; and
 - (iii) subjecting the ground material to mechano-chemical activation to form an activated material.
2. The method according to claim 1, wherein the feed bauxite waste material comprises either or both bauxite residue and bauxite tailings.
3. The method according to either claim 1 or 2, including comminuting the feed bauxite waste material to form feed bauxite waste material having a maximum average particle size of 2 mm.
4. The method according to any one of the preceding claims, including a mixing step comprising adding an additive to the feed bauxite waste material and forming a bauxite waste material mixture comprising up to 35 wt% of the additive.
5. The method according to claim 4, wherein the mixing step includes adding a reactivity-increasing additive or a reducing agent to the feed bauxite waste material.
6. The method according to any one of the preceding claims, wherein the drying step involves drying the feed bauxite waste material to less than 10 wt% water content.
7. The method according to any one of the preceding claims, wherein the comminution step involves grinding the dried material in the absence of a fluid.
8. The method according to any one of the preceding claims, wherein the comminution step involves comminuting the dried material to form a ground material having a maximum average particle size of 15 microns.
9. The method according to any one of the preceding claims, including separating the ground material into a ground coarse fraction and a ground fines fraction.
10. The method according to any one of the preceding claims, wherein the separating step includes classifying the ground material such that the ground coarse fraction size is not greater than twice the lowest ground fines fraction size.
11. The method according to any one of the preceding claims, including subjecting the ground or activated material to a magnetic separation step to remove ferromagnetic material.
12. The method according to any one of the preceding claims, including analysing the activated material and/or the ground material using one or more methods selected from a group comprising IR spectroscopy, RAMAN spectroscopy, X-ray diffraction analysis, LIBS, heat flow calorimetry, thermogravimetry, scanning electron microscopy, particle size and/or particle shape analysis, NMR spectroscopy to determine the reactivity of the activated material.

5 13. The method according to any one of the preceding claims, wherein the mechano-chemical activation involves subjecting the ground material to an energy input of at least 100 kW/m³.

14. The method according to any one of the preceding claims, wherein the mechano-chemical activation includes processing the ground material in a high energy mill operating at a circumferential speed of up to 10 m/s.

10 15. The method according to any one of the preceding claims, wherein the mechano-chemical activation is performed until agglomeration of the ground material occurs.

16. The method according to any one of the preceding claims, including separating the activated material into an activated coarse fraction and an activated fines fraction.

15 17. The method according to claim 16, wherein the separating step includes classifying the activated material such that the activated coarse fraction size is not greater than twice the lowest activated fines fraction size.

18. The method according to either claim 16 or 17, including processing the activated coarse fraction into supplementary cementitious material (SCM).

19. A system for upgrading a feed bauxite waste material, the system comprising:

20 (a) a dryer configured to dry the feed bauxite waste material to form a dried material; and
(b) at least one mill configured to comminute the dried material to form a ground material and subjecting the ground material to mechano-chemical activation to form an activated material.

20. The system according to claim 19, including a comminutor configured to form feed bauxite waste material having a maximum average particle size of 2 mm.

25 21. The system according to either claim 19 or 20, including a mixer configured to mix the feed bauxite waste material with an additive to form a mixture comprising up to 35 wt% of the additive.

30 22. The system according to any one of claims 19 to 21, including a ground material classifier configured to separate the ground material into a ground coarse fraction and a ground fines fraction.

23. The system according to any one of claims 19 to 22, including an activated material classifier configured to separate the activated material into an activated coarse fraction and an activated fines fraction.

35 24. The system according to any one of claims 19 to 23, including a magnetic separator configured to remove ferromagnetic material from either or both the ground and activated materials.

25. The system according to any one of claims 19 to 24, including a first mill to form the ground material and a second mill to form the activated material.

26. The system according to any one of claims 19 to 24, including one mill for forming the ground and activated materials.

5 27. The system according to claim 25, wherein a magnetic separator is located between the first and second mills.

 28. The system according to claim 25, wherein a magnetic separator is located downstream of the first and second mills.

10 29. The system according to any one of claims 19 to 28, including an SCM recovery unit to isolate SCM from the activated material.

 30. The system according to any one of claims 19 to 29, including a controller for classifying the ground material such that the ground coarse fraction size is not greater than twice the lowest ground fines fraction size.

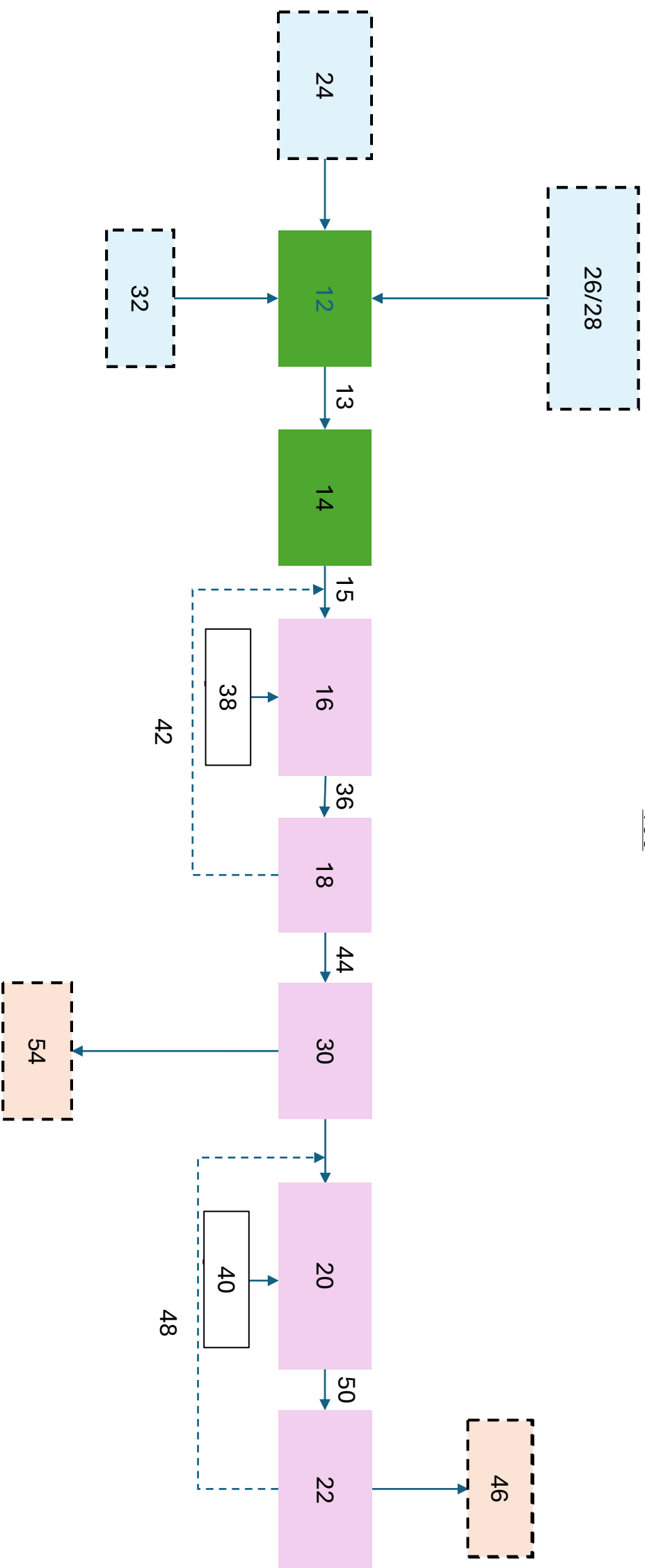
15 31. The system according to any one of claims 19 to 30, including a controller for classifying the activated material such that the activated coarse fraction size is not greater than twice the lowest activated fines fraction size.

 32. The system according to any one of claims 27 to 31, including an analyser for analysing the ground material and/or the activated material to characterise the material entering and/or exiting the magnetic separator.

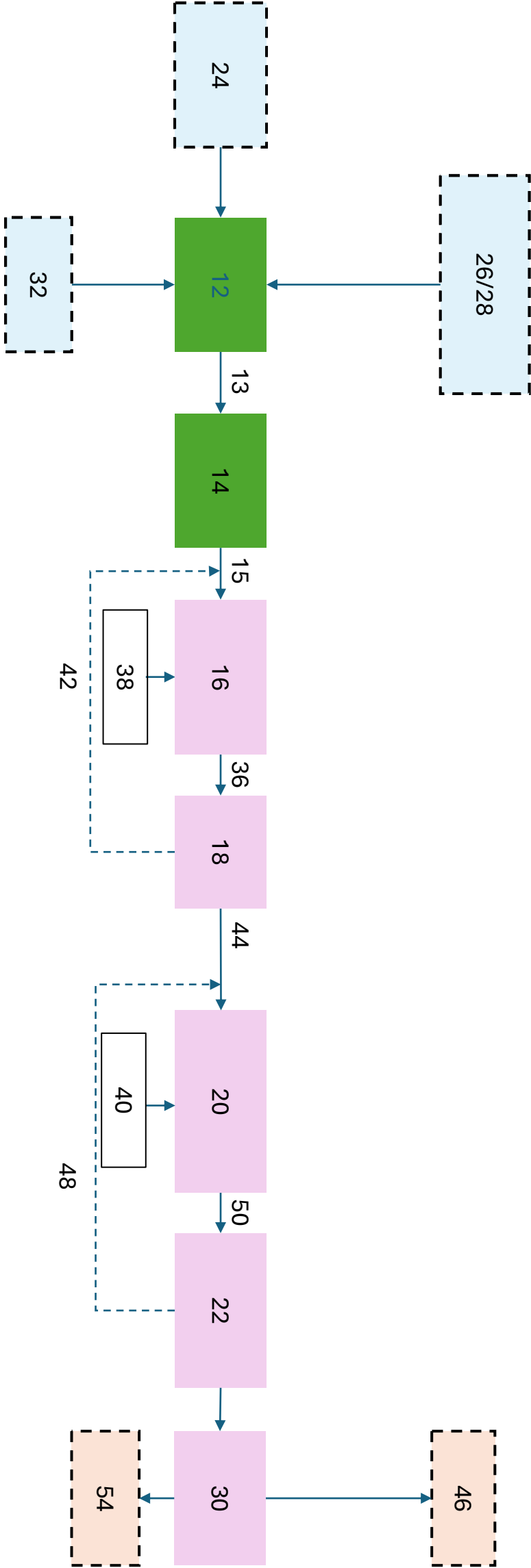
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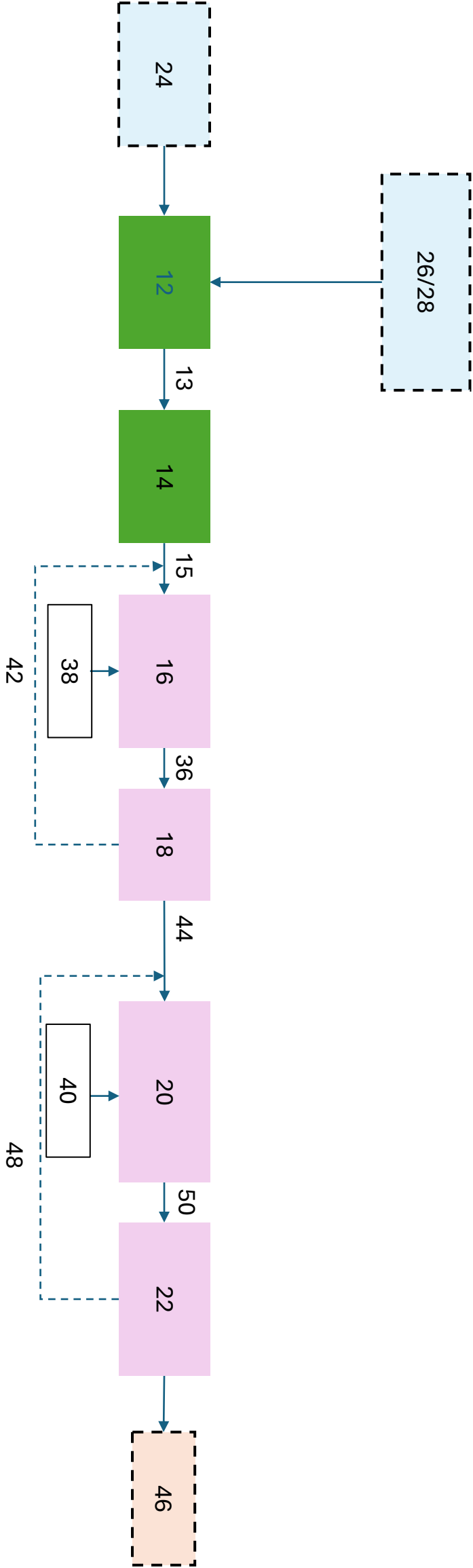
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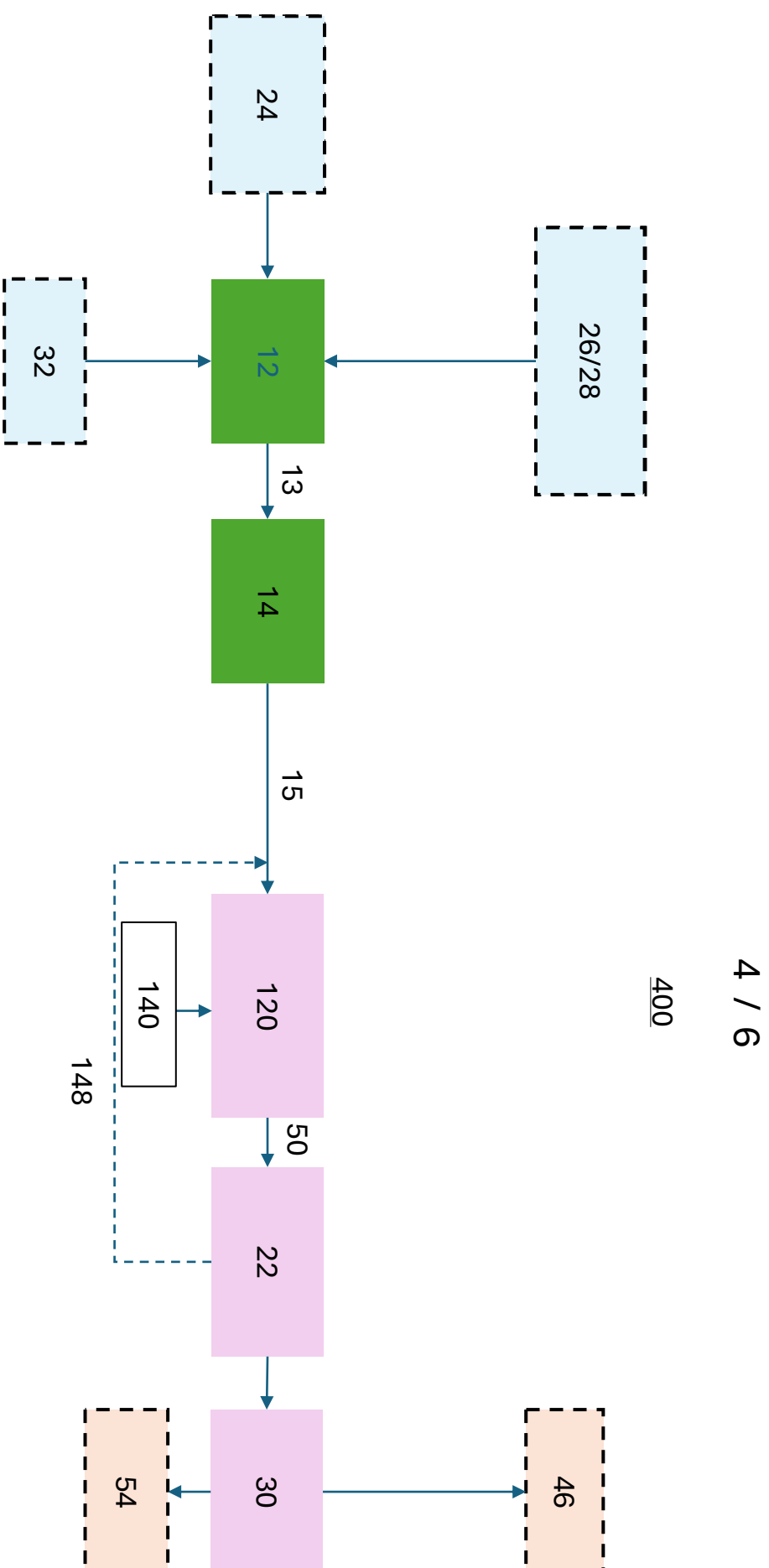


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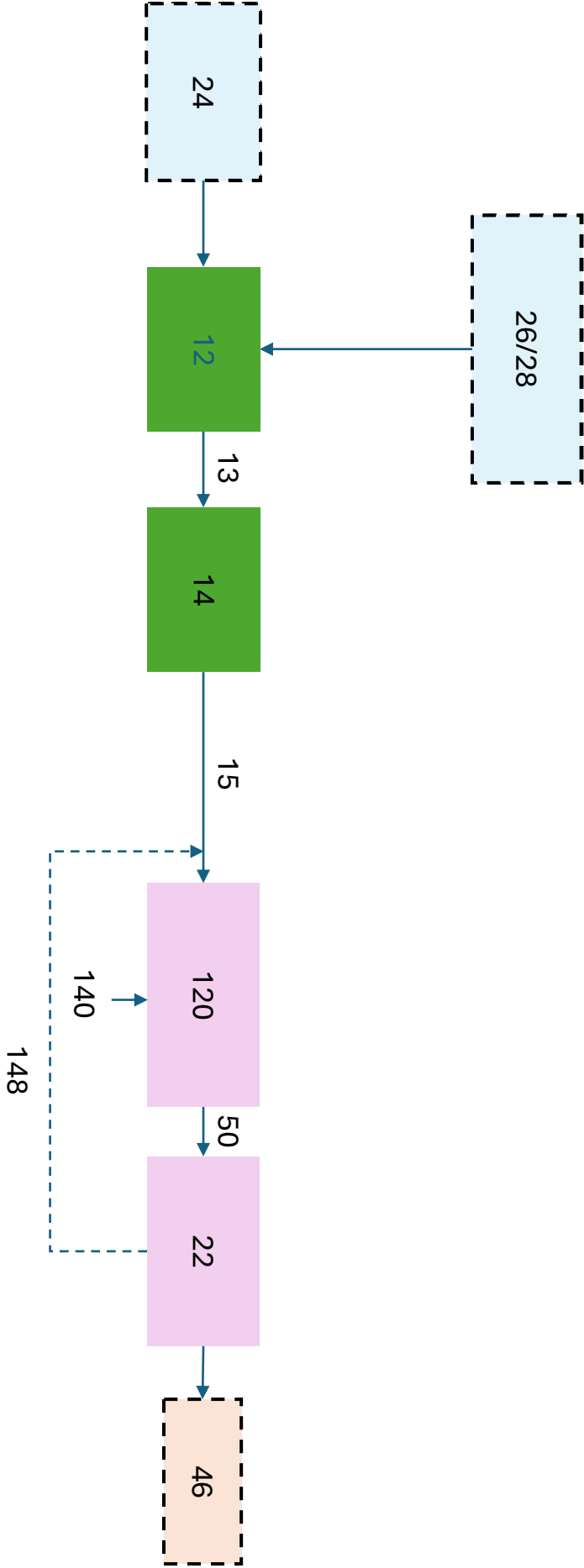


300





500



Feedstock blend						Flowsheet Option	
Bauxite Residue (BR) (wt%)			Bauxite tailing (wt%)		Kaolin content	Kaolin purity (wt% kaolinite)	
BR1	BR2	BR3	Ultrafine fraction	Coarse fraction			
65	-	-	-	-	~35	~100	3
65	-	-	-	-	~35	~60	3
80	-	-	-	-	~20	~100	3
80	-	-	-	-	~20	~60	3
80	-	-	-	-	~20	~100	5
80	-	-	-	-	~20	~60	5
80	-	-	-	-	~20	~60	5
80	-	-	-	-	~20	~100	1
80	-	-	-	-	~20	~60	1
80	-	-	-	-	~20	~100	2
80	-	-	-	-	~20	~60	2
80	-	-	-	-	~20	~100	4
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-	65	-	~35	-	-	-	3
-	80	-	~20	-	-	-	3
-	65	-	-	~35	-	-	3
-	80	-	-	~20	-	-	3
-	-	80	-	~20	-	-	3
-	-	80	~20	-	-	-	3
-	-	80	-	~20	-	-	3
-	-	80	~20	-	-	-	5
-	-	80	-	~20	-	-	5