

SYSTEM AND METHOD FOR CONVERTING WASTE PLASTIC MATERIALS TO USEFUL PRODUCTS, AND SOLID COMPRESSION UNIT

Technical Field

[0001] Various embodiments generally relate to a system and a method for converting
5 waste plastic materials to useful products, and a solid compression unit for the system. In
particular, various embodiments generally relate to a pyrolysis system and a pyrolysis
method for converting waste plastic materials to useful products, and a solid compression
unit for the pyrolysis system.

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Background

[0002] Generally, waste plastics can be converted to useful gas, liquid and/or solid
products through a pyrolysis process. However, many challenges are hindering the adoption
of the pyrolysis process for waste plastics. The challenges include, for example, inconsistent
quality and mixture of waste plastic raw material/feedstock or contaminated waste plastic
15 raw material/feedstock which requires costly sorting and/or pre-treatment to ensure the
quality of the raw material/feedstock for the pyrolysis process. Another challenge lies in the
difficulty to control and to achieve a desired pyrolysis product which leads to purpose-built
pyrolysis systems/apparatus for specific waste plastics product raw material/feedstock and
which are costly.

20 **[0003]** Accordingly, there is a need to provide a more efficient and versatile system and a
method for pyrolysis of waste plastic materials that address the above problems.

Summary

[0004] According to various embodiments, a system for converting waste plastic materials
25 to useful products may be provided. The system may include a continuous thermal treatment
arrangement. According to various embodiments, the continuous thermal treatment
arrangement may include a melting stage to melt a compressed waste plastic feed generated
from the waste plastic materials so as to form a melted mixture. According to various
embodiments, the continuous thermal treatment arrangement may further include a thermal-
30 to-catalytic pyrolysis stage downstream of the melting stage to subject the melted mixture
through a thermal pyrolysis process followed by a catalytic pyrolysis process for producing

a pyrolysis gas product and a pyrolysis solid residue. According to various embodiments, the thermal-to-catalytic pyrolysis stage may include at least two catalyst feeding points distributed along the thermal-to-catalytic pyrolysis stage. According to various embodiments, the thermal-to-catalytic pyrolysis stage may be operable to selectively feed a catalyst via any one or more of the at least two catalyst feeding points for transforming the thermal pyrolysis process to the catalytic pyrolysis process at different points along the thermal-to-catalytic pyrolysis stage in a manner so as to vary a proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage. According to various embodiments, the continuous thermal treatment arrangement may further include a termination stage downstream of the thermal-to-catalytic pyrolysis stage to heat the pyrolysis solid residue for conversion into a solid product.

[0005] According to various embodiments, a method of converting waste plastic materials to useful products may be provided. According to various embodiments, the method may include introducing a compressed waste plastic feed generated from the waste plastic materials to a melting stage of a continuous thermal treatment arrangement of a system for converting waste plastic materials to useful products. According to various embodiments, the melting stage may melt the compressed waste plastic feed to form a melted mixture. The method may further include selectively feeding a catalyst via any one or more of at least two catalyst feeding points of a thermal-to-catalytic pyrolysis stage of the continuous thermal treatment arrangement of the system to vary a proportion of a thermal pyrolysis process and a catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage based on a desired final product to be output from the system or a property of the waste plastic materials or feed that is introduced to the system. According to various embodiments, the thermal-to-catalytic pyrolysis stage may be downstream of the melting stage and may subject the melted mixture through the thermal pyrolysis process followed by the catalytic pyrolysis process for producing a pyrolysis gas product and a pyrolysis solid residue. The method may further include removing a solid product from a termination stage of the continuous thermal treatment arrangement of the system. According to various embodiments, the termination stage may be downstream of the thermal-to-catalytic pyrolysis stage and heats the pyrolysis solid residue for conversion into the solid product.

[0006] According to various embodiments, there is provided a solid compression unit comprising at least two rotatable screws arranged in series from an entrance of the solid compression unit to an exit of the solid compression unit, wherein the at least two rotatable

screws are cooperatively operable to compress solid materials as the at least two rotatable screws move the solid materials from the entrance of the solid compression unit to the exit of the solid compression unit.

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Brief description of the drawings

[0007] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments are described with reference to the following drawings, in which:

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FIG. 1A shows a schematic diagram of a system for converting waste plastic materials to useful products according to various embodiments;

FIG. 1B shows a schematic diagram of a compression unit of the system of FIG. 1A according to various embodiments; and

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FIG. 1C shows a schematic diagram of a secondary compression unit of the system of FIG. 1A according to various embodiments.

Detailed description

[0008] Embodiments described below in the context of the apparatus are analogously valid for the respective methods, and vice versa. Furthermore, it will be understood that the embodiments described below may be combined, for example, a part of one embodiment may be combined with a part of another embodiment.

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[0009] It should be understood that the terms “on”, “over”, “top”, “bottom”, “down”, “side”, “back”, “left”, “right”, “front”, “lateral”, “side”, “up”, “down” etc., when used in the following description are used for convenience and to aid understanding of relative positions or directions, and not intended to limit the orientation of any device, or structure or any part of any device or structure. In addition, the singular terms “a”, “an”, and “the” include plural references unless context clearly indicates otherwise. Similarly, the word “or” is intended to include “and” unless the context clearly indicates otherwise.

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[00010] Various embodiments generally relate to a system for converting waste plastic materials to useful product and a method of converting waste plastic materials to useful product. According to various embodiments, the waste plastic materials may include, but

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not limited to, municipal waste materials which may include various types of polymer, e.g. polypropylene, polyethylene etc. According to various embodiments, the useful product may include, but not limited to, hydrocarbon having carbon atoms in the range of C₂ to C₃₄, preferably hydrocarbon that is suitable for petrochemical process or fuel (e.g. Naphtha, Diesel or other hydrocarbon products), and a solid product. According to various embodiments, the solid product may include, but not limited to, solid carbon (e.g. carbon black), or other solid included in the waste plastic materials etc. Various embodiments generally relate to a pyrolysis system for converting waste plastic materials to useful products and a pyrolysis method of converting waste plastic materials to useful products. Accordingly, various embodiments may seek to provide a system and a method for thermal decomposition or degradation of the waste plastic materials into useful products. According to various embodiments, the system may include an apparatus or arrangement or equipment to perform thermal treatment for pyrolysis of the waste plastic materials.

[00011] According to various embodiments, the system may include a thermal treatment arrangement or apparatus or equipment for performing pyrolysis of the waste plastic materials. According to various embodiments, the thermal treatment arrangement may be configured to perform a thermal treatment sequence including a thermal pyrolysis process followed by a catalytic pyrolysis process. According to various embodiments, the thermal treatment arrangement may be configured to vary or adjust or alter a proportion of the thermal pyrolysis process and the catalytic pyrolysis process performed on the waste plastic materials within the thermal treatment arrangement so as to change or vary a final product generated from the waste plastic materials by the system. Accordingly, depending on the desired final product, the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal treatment arrangement may be varied or adjusted or altered so as to subject the waste plastic materials to the thermal treatment sequence having the required proportion of the thermal pyrolysis process and the catalytic pyrolysis process to generate the desired final product. According to various embodiments, the proportion of the thermal pyrolysis process and the catalytic pyrolysis process may be a ratio of a duration (or retention time) of the thermal pyrolysis process to a duration (or retention time) of the catalytic pyrolysis process.

[00012] According to various embodiments, the thermal treatment arrangement may include at least two (e.g. two or more) catalyst feeding points along the thermal treatment arrangement for feeding a catalyst into the thermal treatment arrangement to transform the

thermal pyrolysis process to the catalytic pyrolysis process at different points along the thermal treatment arrangement so as to vary a point along the thermal treatment arrangement whereby the thermal pyrolysis process switch to the catalytic pyrolysis process. According to various embodiments, the system and method may include selectively varying a point
5 along the thermal treatment arrangement where the catalyst is added to transform or change or switch or convert the thermal pyrolysis process to the catalytic pyrolysis process based on the desired final product to be output from the system or a property of the waste plastic materials or feed that is introduced to the system. For example, according to various embodiments, the catalyst may be selectively added in any one or more of the at least two
10 catalyst feeding ports of the thermal treatment arrangement so as to achieve or attain or realize the proportion of the thermal pyrolysis process and the catalytic pyrolysis process required, with the thermal pyrolysis process transforming or changing or switching or converting to the catalytic pyrolysis process by the feeding or addition of the catalyst at the required points along the thermal treatment arrangement. Accordingly, the catalyst may be
15 added or fed or input at a point where the catalytic pyrolysis process is to take place. For example, according to various embodiments, the catalyst may be selectively added in a zone or a stage or a chamber or reactor where the catalytic pyrolysis process is to take place. Various embodiments is distinct and different from conventional catalytic pyrolysis system and method whereby a catalyst is typically mixed with the waste plastic materials at a
20 feeding stage (e.g. raw materials feeding zone).

[00013] According to various embodiments, with the proportion of the thermal pyrolysis process and the catalytic pyrolysis process along the thermal treatment arrangement being variable or adjustable to generate the desired final product output from the system, various embodiments have provided a versatile and efficient system and method. Various
25 embodiments may be able to accept wide variety of waste plastic materials including, but not limited to, inconsistent quality and mixture of waste plastic materials or contaminated waste plastic materials, and to generate the desired final product output by varying the proportion of the thermal pyrolysis process and the catalytic pyrolysis process along the thermal treatment arrangement. Further, various embodiments may also allow or provide a
30 simple and easy feedback control for the final product via monitoring the final product output from the system and varying the proportion of the thermal pyrolysis process and the catalytic pyrolysis process along the thermal treatment arrangement to adjust or fine-tune the final product output from the system.

[00014] According to various embodiments, by selectively varying the point or points along the system where the catalyst is to be added such that the catalyst may be selectively added in the same zone or stage or chamber or reactor where catalytic pyrolysis actually takes place, an ideal amount of catalyst may be determined, measured and added to the system without wastage of the catalyst. Further, the catalyst may be added at a point of the system of various embodiments where the waste plastic material contained therein is already broken down into a size that is small enough to fit into the pore sites of the catalyst used. Thus, all the catalyst added in the system and methods according to various embodiments may perform their function with minimal or no wastage. According to various embodiments, the catalyst is not be mixed together with the waste plastic feed at the start of the system or process (e.g. at a raw materials feeding zone). Therefore, various embodiments may avoid or minimize wastage or deactivation of the catalyst such as the molecules of the waste plastic feed being too large to enter the pore site of the catalyst or these large molecules of waste plastic feed blocking the pore site of the catalyst before the catalyst may be activated. Accordingly, the system and method according to various embodiments may lead to cost saving from no or minimal wastage of catalyst.

[00015] Various embodiments also relate to a solid compression unit for the system as described herein. According to various embodiments, the system may include at least one solid compression unit to compress the waste plastic materials before feeding into the thermal treatment arrangement. Accordingly, the at least one solid compression unit may compress the waste plastic materials to remove moisture and air so as to prevent moisture and air from entering the thermal treatment arrangement. According to various embodiments, the system may also include at least one other solid compression unit for removing a solid product from the thermal treatment arrangement. According to various embodiments, the solid product may be remove from the system without shutting down the process by the at least one other solid compression unit. According to various embodiments, the solid compression unit may include at least two rotatable screws arranged in series which are operable to decrease a volumetric rate of flow of solid from one rotatable screw to a subsequent rotatable screw. Due to the decrease in the volumetric rate of flow generated by each of the at least two rotatable screws, the solid (e.g. the waste plastic materials or the solid product) may be compressed into a compressed solid as the solid is move along the at least two rotatable screws. Thus, by way of decreasing the volumetric rate of flow of the at least two rotatable screws arranged in series, the solid may move at different volumetric rate

of flow along different segments of the solid compression unit, whereby the volumetric rate of flow between the different segments are decreasing from an entrance to an exit of the solid compression unit. According to various embodiments, the solid (e.g. the waste plastic materials or the solid product) may be compressed or compacted by the solid compression unit to prevent air from entering the system and/or prevent the leaking of gas product generated from the system to the atmosphere during operation of the system or feeding of the waste plastic materials and/or removal of the solid product.

[00016] The following examples pertain to various embodiments:

[00017] Example 1 is a system for converting waste plastic materials to useful products, including: a continuous thermal treatment arrangement. The continuous thermal treatment arrangement may include a melting stage to melt a compressed waste plastic feed generated from the waste plastic materials so as to form a melted mixture. The continuous thermal treatment arrangement may further include a thermal-to-catalytic pyrolysis stage downstream of the melting stage to subject the melted mixture through a thermal pyrolysis process followed by a catalytic pyrolysis process for producing a pyrolysis gas product and a pyrolysis solid residue. The thermal-to-catalytic pyrolysis stage may include at least two catalyst feeding points distributed along the thermal-to-catalytic pyrolysis stage. The thermal-to-catalytic pyrolysis stage may be operable to selectively feed a catalyst via any one or more of the at least two catalyst feeding points for transforming the thermal pyrolysis process to the catalytic pyrolysis process at different points along the thermal-to-catalytic pyrolysis stage in a manner so as to vary a proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage. The continuous thermal treatment arrangement may further include a termination stage downstream of the thermal-to-catalytic pyrolysis stage to heat the pyrolysis solid residue for conversion into a solid product.

[00018] In Example 2, the subject matter of Example 1 may optionally include: a waste materials compression unit upstream of the continuous thermal treatment arrangement. The waste materials compression unit may be operable to compress the waste plastic materials to remove air and moisture so as to generate the compressed waste plastic feed for feeding into the continuous thermal treatment arrangement.

[00019] In Example 3, the subject matter of Example 1 or Example 2 may optionally include: wherein a temperature range of the termination stage is higher than a temperature

range of the thermal-to-catalytic pyrolysis stage, and the temperature range of the thermal-to-catalytic pyrolysis stage is higher than a temperature range of the melting stage.

[00020] In Example 4, the subject matter of any one of Examples 1 to 3 may optionally include: wherein the thermal-to-catalytic pyrolysis stage includes an initial thermal
5 pyrolysis zone to heat the melted mixture received from the melting stage at or above a thermal decomposition temperature of the melted mixture, one or more intermediate variable zones, each intermediate variable zone having a catalyst feeding port at a start of the intermediate variable zone, the catalyst feeding port serving as one of the at least two catalyst feeding points along the thermal-to-catalytic pyrolysis stage, and a final catalytic
10 pyrolysis zone having a catalyst feeding port at a start of the final catalytic pyrolysis zone serving as a final catalyst feeding point of the at least two catalyst feeding points along the thermal-to-catalytic pyrolysis stage for receiving the catalyst. The catalyst may be fed through the catalyst feeding port of the one or more intermediate variable zones or the catalyst feeding port of the final catalytic pyrolysis zone for transforming the thermal
15 pyrolysis process to the catalytic pyrolysis process at the different points along the thermal-to-catalytic pyrolysis stage.

[00021] In Example 5, the subject matter of Example 4 may optionally include: wherein the final catalytic pyrolysis zone of the thermal-to-catalytic pyrolysis stage includes at least one pyrolysis gas outlet to release the pyrolysis gas product.

20 **[00022]** In Example 6, the subject matter of any one of Examples 1 to 5 may optionally include: wherein the termination stage includes at least one pyrolysis gas outlet to release the pyrolysis gas product.

[00023] In Example 7, the subject matter of any one of Examples 1 to 6 may optionally include: wherein the termination stage includes at least one solid product outlet for
25 discharging the solid product.

[00024] In Example 8, the subject matter of any one of Examples 1 to 7 may optionally include: wherein the continuous thermal treatment arrangement includes a reactor including the thermal-to-catalytic pyrolysis stage.

[00025] In Example 9, the subject matter of any one of Examples 1 to 7 may optionally
30 include: wherein the continuous thermal treatment arrangement includes a reactor including the melting stage and the thermal-to-catalytic pyrolysis stage.

[00026] In Example 10, the subject matter of any one of Examples 1 to 7 may optionally include: wherein the continuous thermal treatment arrangement includes a reactor including the thermal-to-catalytic pyrolysis stage and the termination stage.

5 **[00027]** In Example 11, the subject matter of any one of Examples 1 to 7 may optionally include: wherein the continuous thermal treatment arrangement includes a reactor including the melting stage, the thermal-to-catalytic pyrolysis stage and the termination stage.

[00028] In Example 12, the subject matter of any one of Examples 8 to 11 may optionally include: wherein the reactor includes a cylindrical shaped reactor.

10 **[00029]** In Example 13, the subject matter of any one of Examples 8 to 12 may optionally include: wherein the reactor includes a conveyor mechanism configured to transport materials along an entire length of the reactor.

[00030] In Example 14, the subject matter of Example 13 may optionally include: wherein the conveyor mechanism includes at least one screw conveyor extending along the entire length of the reactor.

15 **[00031]** In Example 15, the subject matter of any one of Examples 8 to 14 may optionally include: wherein the reactor is inclined in a rise per run ratio of 1:250-1:20.

[00032] In Example 16, the subject matter of any one of Examples 8 to 15 may optionally include: wherein the reactor is inclined in a rise per run ratio of 1:200-1:50.

20 **[00033]** In Example 17, the subject matter of any one of Examples 8 to 16 may optionally include: wherein the reactor is inclined in a rise per run ratio of 1:150-1:80.

[00034] In Example 18, the subject matter of any one of Examples 1 to 17 may optionally include: wherein the waste materials compression unit includes at least a first rotatable screw and a second rotatable screw arranged in series, wherein the waste plastic materials are fed into the waste materials compression unit at a first end of the first rotatable screw and moved
25 through the waste materials compression unit via the first rotatable screw followed by the second rotatable screw.

[00035] In Example 19, the subject matter of Example 18 may optionally include: wherein a rotational speed of the first rotatable screw of the waste materials compression unit is faster than a rotational speed of the second rotatable screw of the waste materials
30 compression.

[00036] In Example 20, the subject matter of Example 18 may optionally include: wherein a diameter of a screw shaft of the first rotatable screw is smaller than a diameter of a screw shaft of the second rotatable screw.

[00037] In Example 21, the subject matter of Example 18 may optionally include: wherein a pitch range of the first rotatable screw is larger than a pitch of the second rotatable screw.

[00038] In Example 22, the subject matter of Examples 1 to 21 may optionally include at least one solid product compression unit to compress the solid product discharge from the termination stage of the continuous thermal treatment arrangement, wherein the solid product compression unit is downstream of the termination stage of the continuous thermal treatment arrangement

[00039] In Example 23, the subject matter of Example 22 may optionally include: wherein the solid product compression unit includes a first rotatable screw and a second rotatable screw.

[00040] In Example 24, the subject matter of Example 23 may optionally include: wherein the first rotatable screw of the solid product compression unit and the second rotatable screw of the solid product compression unit are arranged in series.

[00041] In Example 25, the subject matter of Example 23 or Example 24 may optionally include: wherein the first rotatable screw of the solid product compression unit and the second rotatable screw of the solid product compression unit have a same pitch range of 70 mm to 220 mm, or 80 mm to 200 mm.

[00042] In Example 26, the subject matter of Examples 23 to 25 may optionally include: wherein the second rotatable screw of the solid product compression unit have a rotation speed of 40% to 100%, or 55% to 98%, or 70% to 97%, or 80% to 95%, of that of the first rotatable screw of the solid product compression unit.

[00043] In Example 27, the subject matter of any one of Examples 22 to 26 may optionally include: wherein the solid product compression unit further includes a third rotatable screw.

[00044] In Example 28, the subject matter of Example 27 may optionally include: wherein the first rotatable screw of the solid product compression unit, the second rotatable screw of the solid product compression unit, and the third rotatable screw of the solid product compression unit are arranged in series.

[00045] In Example 29, the subject matter of Example 27 or Example 28 may optionally include: wherein the first rotatable screw of the solid product compression unit, the second rotatable screw of the solid product compression unit, and the third rotatable screw of the solid product compression unit have the same pitch range.

[00046] In Example 30, the subject matter of any one of Examples 27 to 29 may optionally include: wherein the third rotatable screw of the solid product compression unit have a

rotation speed of 35% to 97%, or 40% to 95%, or 50% to 90%, or 60% to 88%, or 70% to 85% of that of the first rotatable screw of the solid product compression unit.

5 **[00047]** In Example 31, the subject matter of Examples 23 to 30 may optionally include: wherein the solid product compression unit further including one or more addition rotatable screws.

[00048] In Example 32, the subject matter of Example 23 may optionally include: wherein a pitch range of the first rotatable screw of the solid product compression unit is larger than a pitch range of the second rotatable screw of the solid product compression unit, wherein the pitch range of the second rotatable screw of the solid product compression unit is 70%
10 to 100%, or 75% to 99%, or 78% to 98% of that of the first rotatable screw of the solid product compression unit.

[00049] In Example 33, the subject matter of Example 23 may optionally include a third rotatable screw, wherein a pitch range of the first rotatable screw of the solid product compression unit is larger than a pitch range of the second rotatable screw of the solid
15 product compression unit, and the pitch range of the second rotatable screw of the solid product compression unit is equal to or larger than a pitch range of the third rotatable screw of the solid product compression unit, wherein the pitch range of the second rotatable screw of the solid product compression unit is 70% to 100%, or 75% to 99%, or 78% to 98% of that of the first rotatable screw of the solid product compression unit, and the pitch range of
20 the third rotatable screw of the solid product compression unit is 65% to 98%, or 75% to 95%, or 80% to 93% of that of the first rotatable screw of the solid product compression unit.

[00050] In Example 34, the subject matter of Examples 23 to 26 may optionally include that: wherein a shaft diameter of the first rotatable screw of the solid product compression
25 unit is smaller than a shaft diameter of the second rotatable screw of the solid product compression unit, wherein the shaft diameter of the second rotatable screw of the solid product compression unit is 100% to 135%, or 105% to 130% of that of the first rotatable screw of the solid product compression unit.

[00051] In Example 35, the subject matter of Examples 23 to 26 may optionally include a
30 third rotatable screw, wherein a shaft diameter of the first rotatable screw of the solid product compression unit is smaller than a shaft diameter of the second rotatable screw of the solid product compression unit, and the shaft diameter of the second rotatable screw of the solid product compression unit is equal to or larger than a shaft diameter of the third

rotatable screw of the solid product compression unit, wherein the shaft diameter of the second rotatable screw of the solid product compression unit is 100% to 135%, or 105% to 130% of that of the first rotatable screw of the solid product compression unit, and the shaft diameter of the third rotatable screw of the solid product compression unit is 105% to 155%, or 108% to 145% of that of the first rotatable screw of the solid product compression unit.

5 **[00052]** In Example 36, the subject matter of any one of Examples 23 to 35 may optionally include: wherein the solid product compression unit further includes a cooling jacket surrounding at least one rotatable screw of the solid product compression unit, wherein a cooling fluid is circulated through the cooling jacket to cool the solid product being compressed.

10 **[00053]** In Example 37, the subject matter of any one of Examples 1 to 36 may optionally include: wherein the termination stage includes a first heating zone to raise a temperature of the solid product and a second heating zone to maintain the solid product at an elevated temperature.

15 **[00054]** In Example 38, the subject matter of any one of Examples 5 to 37 in combination with Example 5 or Example 6 may optionally include: wherein the at least one pyrolysis gas outlet includes a vacuum pump.

20 **[00055]** In Example 39, the subject matter of any one of Examples 5 to 38 in combination with Example 5 or Example 6 may optionally include at least one heat exchanger unit connected to the at least one pyrolysis gas outlet to condense long chain carbon compounds in the pyrolysis gas product.

25 **[00056]** In Example 40, the subject matter of Example 39 may optionally include: wherein the at least one heat exchanger unit is configured to minimize pressure drop in the thermal-to-catalytic pyrolysis stage, wherein the at least one heat exchanger includes a double-pipe heat exchanger or a shell-and-tube heat exchanger, wherein preferably the at least one heat exchanger includes the double-pipe heat exchanger.

30 **[00057]** In Example 41, the subject matter of Example 39 or Example 40 may optionally include at least one gas separator unit downstream of the at least one heat exchanger unit to remove residue particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product.

[00058] In Example 42, the subject matter of Example 41 may optionally include: wherein the at least one gas separator unit includes a cyclone separator or a drum separator.

[00059] In Example 43, the subject matter of Example 41 or Example 42 may optionally include at least one product separation and purification unit downstream of the at least one gas separator unit to separate and purify the pyrolysis gas product to achieve a desired final products.

5 **[00060]** Example 44 is a method of converting waste plastic materials to useful products. The method may include introducing the compressed waste plastic feed generated from the waste plastic materials to the continuous thermal treatment arrangement of the system according to any one of Example 1 to Example 43. The method may include feeding the catalyst via one or more of the at least two catalyst feeding points of the thermal-to-catalytic
10 pyrolysis stage of the continuous thermal treatment arrangement to vary the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage. The method may include removing the solid product from the termination stage of the system.

[00061] In Example 45, the subject matter of Example 44 may optionally include
15 monitoring at least one property of a final product output from the system to determine whether an adjustment of the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage is required for generating the desired final product to be output from the system.

[00062] In Example 46, the subject matter of Example 45 may optionally include feeding
20 the catalyst via one or more of the at least two catalyst feeding points based on the proportion of the thermal pyrolysis process and the catalytic pyrolysis process determined to be required.

[00063] In Example 47, the subject matter of Example 45 or Example 46 may optionally include the at least one property of the final product monitored is specific gravity.

25 **[00064]** In Example 48, the subject matter of any one of Example 44 to Example 47 may optionally include withdrawing the pyrolysis gas product from the continuous thermal treatment arrangement.

[00065] In Example 49, the subject matter of any one of Examples 44 to 48 may optionally include condensing the long chain carbon compounds from the pyrolysis gas product by the
30 at least one heat exchanger unit when the system is according to any one of Example 39 to Example 43.

[00066] In Example 50, the subject matter of Example 49 may optionally include returning the long chain carbon compounds into the thermal-to-catalytic pyrolysis stage.

[00067] In Example 51, the subject matter of any one of Example 44 to 50 may optionally include removing the residue particulate or the heavy hydrocarbon or the combination thereof from the pyrolysis gas product by the at least one gas separator unit when the system is according to any one of Examples 41 to 43.

- 5 **[00068]** In Example 52, the subject matter of Example 51 may optionally include returning the residue particulate or the heavy hydrocarbon or the combination thereof to the thermal-to-catalytic pyrolysis stage.

[00069] In Example 53, the subject matter of Examples 44 to 52 may optionally include: wherein the catalytic pyrolysis process is at a temperature in a range of 250 – 370 °C.

- 10 **[00070]** In Example 54, the subject matter of any one of Examples 44 to 53 may optionally include compressing the waste plastic materials via the waste materials compression unit by a compression ratio in a range of 2.0 to 5.0 when the system is according to any one of Examples 2 to 43 in combination with Example 2.

- [00071]** In Example 55, the subject matter of Example 54 may optionally include:
15 wherein compressing the waste plastic materials via the waste materials compression unit removes air such that the compressed waste plastic feed output from the compression unit has an air (e.g. oxygen) content in the range of 2%wt to 16%wt, preferably 5%wt to 10%wt.

- [00072]** In Example 56, the subject matter of Example 54 or 55 may optionally include:
20 wherein compressing the waste plastic materials via the waste materials compression unit removes moisture such that the compressed waste plastic feed output from the compression unit has a moisture content in a range of 2%wt to 16%wt, preferably 5%wt to 10 %wt.

[00073] In Example 57, the subject matter of any one of Examples 54 to 56 may optionally include: wherein compressing the waste plastic materials via the waste materials compression unit is at a temperature in a range of 90 – 140 °C.

- 25 **[00074]** In Example 58, the subject matter of any one of Examples 54 to 57 may optionally include: wherein compressing the waste plastic materials via the waste materials compression unit is at a pressure in a range of 100 kPa to 150 kPa (or 0 barg to 0.5 barg, or 1 bar to 1.5 bar).

- [00075]** In Example 59, the subject matter of any one of Examples 54 to 58 may optionally
30 include: wherein compressing the waste plastic materials via the waste materials compression unit is for a retention time of 30 seconds to 120 seconds (or 0.5 minutes to 2 minutes).

[00076] to 59 may 44 of any one of Examples In Example 60, the subject matter optionally includemelting the compressed waste plastic feed via the melting stage by heating at a temperature equal to or higher than a melting point of the compressed waste plastic feed, preferably wherein the temperature is in a range of 110 – 160 °C.

- 5 **[00077]** In Example 61, the subject matter of any one of Examples 44 to 60 may optionally include: wherein the thermal pyrolysis process is at a temperature suitable for reducing a molecular size to be equal to or less than a pore size of the catalyst, preferably wherein the temperature is in a range of 130°C to 370°C, preferably 130°C to 280°C.

- 10 **[00078]** In Example 62, the subject matter of any one of Examples 44 to 61 may optionally include heating the pyrolysis solid residue via the termination stage to a temperature suitable for breaking down remaining carbon-hydrogen bond and removing remaining hydrogen and moisture from the pyrolysis solid residue, preferably wherein the temperature is at least 350 °C.

- 15 **[00079]** In Example 63, the subject matter of Example 62 in combination with Example 60 may optionally include: wherein the melting of compressed waste plastic feed, the thermal pyrolysis process, the catalytic pyrolysis process, and the heating of the pyrolysis solid residue are at a same pressure, preferably wherein the same pressure is in the range of 20 kPa to 80 kPa, preferably 40 kPa to 60 kPa (or 0.2 barg to 0.8 barg, preferably 0.4 barg to 0.6 barg, or 1.2 bar to 1.8 bar, preferably 1.4 bar to 1.6 bar).

- 20 **[00080]** In Example 64, the subject matter of Example 60 may optionally include: wherein melting the compressed waste plastic feed via the melting stage is for a retention time of 18 seconds to 90 seconds (or 0.3 minutes to 1.5 minutes).

- 25 **[00081]** In Example 65, the subject matter of any one of Examples 44 to 64 may optionally include: wherein the proportion of the thermal pyrolysis process and the catalytic pyrolysis process includes a proportion of a retention time of the thermal pyrolysis process and a retention time of the catalytic pyrolysis process.

[00082] In Example 66, the subject matter of Example 62 may optionally include: wherein heating the pyrolysis solid residue via the termination stage is for a retention time of 18 seconds to 210 seconds (or 0.3 minutes to 3.5 minutes).

- 30 **[00083]** In Example 67, the subject matter of Example 62 or Example 66 may optionally include: wherein heating the pyrolysis solid residue via the termination stage removes moisture such that the solid product has a moisture content in a range of 5%wt to 35%wt,

preferably 10%wt to 30%wt, and a solid content in a range of 60%wt to 95%wt, preferably 70%wt to 90%wt.

[00084] In Example 68, the subject matter of any one of Examples 44 to 67 may optionally include: wherein when the system is according to any one of Examples 22 to 43 in
5 combination with Example 22, wherein the particle size of the solid product leaving the solid product compression unit is in a range of 30 nm to 500 nm.

[00085] In Example 69, the subject matter of Example 68 may optionally include: wherein the solid product compression unit reduce bulk density such that the solid product has a bulk density in a range of 1.0 g/cm³ to 3.0 g/cm³, preferably 1.4 g/cm³ to 2.2 g/cm³.

10 **[00086]** Example 70 is a solid compression unit including a first screw conveyor and a second screw conveyor.

[00087] In Example 71, the subject matter of Example 70 may optionally include: wherein the first screw conveyor and the second screw conveyor are arranged in series.

[00088] In Example 72, the subject matter of Example 70 or Example 71 may optionally
15 include: wherein the first screw conveyor and the second screw conveyor have a same pitch range of 70 mm to 220 mm, or 80 mm to 200 mm.

[00089] In Example 73, the subject matter of any one of Examples 70 to 72 may optionally include: wherein the second screw conveyor has a rotational speed of 40% to 100%, or 55% to 98%, or 70% to 97%, or 80% to 95% of that of the first screw conveyor.

20 **[00090]** In Example 74, the subject matter of any one of Examples 70 to 72 may optionally include a third screw conveyor.

[00091] In Example 75, the subject matter of Example 74 may optionally include: wherein the first screw conveyor, the second screw conveyor, and the third screw conveyor are arranged in series.

25 **[00092]** In Example 76, the subject matter of Example 74 or Example 75 may optionally include: wherein the first screw conveyor, the second screw conveyor, and the third screw conveyor have a same pitch range.

[00093] In Example 77, the subject matter of any one of Examples 74 to 76 may optionally include: wherein the third screw conveyor has a rotation speed of 35% to 97%, or 40% to
30 95%, or 50% to 90%, or 60% to 88%, or 70% to 85% of that of the first screw conveyor.

[00094] In Example 78, the subject matter of any one of Examples 70 to 77 may optionally include one or more addition screw conveyor.

[00095] In Example 79, the subject matter of Example 70 may optionally include: wherein a pitch range of the first screw conveyor is larger than a pitch range of the second screw conveyor, wherein the pitch range of the second screw conveyor is 70% to 100%, or 75% to 99%, or 78% to 98% of that of the first screw conveyor.

5 **[00096]** In Example 80, the subject matter of Example 79 may optionally include a third screw conveyor, wherein the pitch range of the first screw conveyor is larger than the pitch range of the second screw conveyor, and the pitch range of the second screw conveyor is the same of larger than a pitch range of the third screw conveyor, wherein the pitch range of the second screw conveyor is 70% to 100%, or 75% to 99% or 78% to 98% of that of the
10 first screw conveyor., and the pitch range of the third screw conveyor is 65% to 98%, or 75% to 95%, or 80% to 93% of that of the first screw conveyor.

[00097] In Example 81, the subject matter of Example 70 may optionally include: wherein the shaft diameter of the first screw conveyor is smaller than the shaft diameter of the second screw conveyor, wherein the shaft diameter of the second screw conveyor is 100% to 135%,
15 or 105% to 130% of that of the first screw conveyor.

[00098] In Example 82, the subject matter of Example 81 may optionally include a third screw conveyor, wherein the shaft diameter of the first screw conveyor is smaller than the second screw conveyor, and the shaft diameter of the second screw conveyor is the same or smaller than the third screw conveyor, wherein preferably the shaft diameter of the second
20 screw conveyor is 100% to 135%, or 105% to 130% of that of the first screw conveyor, and wherein preferably the shaft diameter of the third screw conveyor is the same as the shaft diameter of the second screw conveyor or the shaft diameter of the third screw conveyor is 105% to 155%, or 108% to 145% of the shaft diameter of the first screw conveyor.

[00099] In Example 83, the subject matter of any one of Examples 70 to 81 may optionally
25 include a cooling jacket surrounding at least one screw conveyor.

[000100] In Example 84, the subject matter of Example 4 may optionally include: wherein the continuous thermal treatment arrangement includes at least one pyrolysis gas outlet to release the pyrolysis gas product, wherein the at least one pyrolysis gas outlet is at the final catalytic pyrolysis zone of the thermal-to-catalytic pyrolysis stage or the termination stage
30 or both, wherein the at least one pyrolysis gas outlet includes a vacuum pump.

[000101] In Example 85, the subject matter of Example 84 may optionally include: at least one heat exchanger unit connected to the at least one pyrolysis gas outlet to condense long chain carbon compounds in the pyrolysis gas product, wherein the at least one heat

exchanger unit is configured to minimize pressure drop in the thermal-to-catalytic pyrolysis stage, wherein the at least one heat exchanger includes a double-pipe heat exchanger or shell-and-tube heat exchanger.

5 **[000102]** In Example 86, the subject matter of Example 85 may optionally include: at least one gas separator unit downstream of the at least one heat exchanger unit to remove residue particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product.

[000103] In Example 87, the subject matter of any one of Examples 1 to 4 and Examples 84 to 86 may optionally include: wherein the termination stage includes at least one solid product outlet for discharging the solid product.

10 **[000104]** In Example 88, the subject matter of any one of Examples 1 to 4 and Examples 84 to 87 may optionally include: wherein the continuous thermal treatment arrangement includes a reactor including any one or a combination of the melting stage, the thermal-to-catalytic pyrolysis stage, or the termination stage.

15 **[000105]** In Example 89, the subject matter of Example 88 may optionally include: wherein the reactor is inclined in a rise per run ratio of 1:250-1:20.

[000106] In Example 90, the subject matter of any one of Examples 2 to 4 and Examples 84 to 89 in combination with Example 2 may optionally include: wherein the waste materials compression unit includes at least two rotatable screws arranged in series from an entrance of the waste materials compression unit to an exit of the waste materials compression unit,
20 wherein a direction of solid transfer is from the entrance of the waste materials compression unit to the exit of the waste materials compression unit.

[000107] In Example 91, the subject matter of Example 90 may optionally include: wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the waste materials compression unit decreases sequentially one after another from the
25 entrance of the waste materials compression unit to the exit of the waste materials compression unit to compress the waste plastic materials into the compressed waste plastic feed.

[000108] In Example 92, the subject matter of Example 91 may optionally include: wherein a diameter of a screw shaft of each of the at least two rotatable screws of the waste
30 materials compression unit increases sequentially one after another from the entrance of the waste materials compression unit to the exit of the waste materials compression unit.

[000109] In Example 93, the subject matter of Example 91 may optionally include: wherein a pitch range of each of the at least two rotatable screws of the waste materials

compression unit may decrease sequentially, one rotatable screw after another rotatable screw, from the entrance of the waste materials compression unit to the exit of the waste materials compression unit.

5 **[000110]** In Example 94, the subject matter of any one of Examples 1 to 4 and Examples 84 to 93 may optionally include: at least one solid product compression unit to compress the solid product discharge from the termination stage of the continuous thermal treatment arrangement, wherein the solid product compression unit is downstream of the termination stage of the continuous thermal treatment arrangement.

10 **[000111]** In Example 95, the subject matter of Example 94 may optionally include: wherein the solid product compression unit includes at least two rotatable screws arranged in series from an entrance of the solid product compression unit to an exit of the solid product compression unit, wherein a direction of solid transfer is from the entrance of the solid product compression unit to the exit of the solid product compression unit.

15 **[000112]** In Example 96, the subject matter of Example 95 may optionally include: wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit to compress the solid product.

20 **[000113]** In Example 97, the subject matter of Example 95 may optionally include: wherein a pitch range of each of the at least two rotatable screws of the solid product compression unit decreases sequentially, one rotatable screw after another rotatable screw, from the entrance of the solid product compression unit to the exit of the solid product compression unit.

25 **[000114]** In Example 98, the subject matter of Example 95 may optionally include: wherein a diameter of a screw shaft of each of the at least two rotatable screws of the solid product compression unit increases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit.

30 **[000115]** In Example 99, the subject matter of Examples 95 may optionally include: wherein a rotational speed of each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit.

[000116] In Example 100, the subject matter of any one of Examples 95 to 99 may optionally include: wherein the solid product compression unit further comprises at least three rotatable screws.

[000117] Example 101 is a method of converting waste plastic materials to useful products, including: introducing a compressed waste plastic feed generated from the waste plastic materials to a melting stage of a continuous thermal treatment arrangement of a system for converting waste plastic materials to useful products, wherein the melting stage melts the compressed waste plastic feed to form a melted mixture. The method may further include selectively feeding a catalyst via any one or more of at least two catalyst feeding points of a thermal-to-catalytic pyrolysis stage of the continuous thermal treatment arrangement of the system to vary a proportion of a thermal pyrolysis process and a catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage (e.g. based on a desired final product to be output from the system or a property of the waste plastic materials or feed that is introduced to the system), wherein the thermal-to-catalytic pyrolysis stage is downstream of the melting stage and subjects the melted mixture through the thermal pyrolysis process followed by the catalytic pyrolysis process for producing a pyrolysis gas product and a pyrolysis solid residue. The method may further include removing a solid product from a termination stage of the continuous thermal treatment arrangement of the system, wherein the termination stage is downstream of the thermal-to-catalytic pyrolysis stage and heats the pyrolysis solid residue for conversion into the solid product.

[000118] In Example 102, the subject matter of Example 101 may optionally include: monitoring at least one property of a final product output from the system to determine whether an adjustment of the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage is required for generating the desired final product to be output from the system, and selectively feeding the catalyst via any one or more of the at least two catalyst feeding points based on the proportion of the thermal pyrolysis process and the catalytic pyrolysis process determined to be required.

[000119] In Example 103, the subject matter of Example 101 or 102 may optionally include: withdrawing the pyrolysis gas product from the continuous thermal treatment arrangement via at least one pyrolysis gas outlet of the continuous thermal treatment arrangement.

[000120] In Example 104, the subject matter of Example 103 may optionally include: condensing long chain carbon compounds from the pyrolysis gas product by at least one

heat exchanger unit connected to the at least one pyrolysis gas outlet, and returning the long chain carbon compounds into the thermal-to-catalytic pyrolysis stage.

5 **[000121]** In Example 105, the subject matter of Example 104 may optionally include: removing residue particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product by at least one gas separator unit downstream of the at least one heat exchanger unit, and returning the residue particulate or the heavy hydrocarbon or the combination thereof to the thermal-to-catalytic pyrolysis stage.

10 **[000122]** In Example 106, the subject matter Example 104 or 105 may optionally include: compressing the waste plastic materials via a waste materials compression unit, wherein the waste materials compression unit is upstream of the continuous thermal treatment arrangement of the system for converting waste plastic materials to useful products.

15 **[000123]** In Example 107, the subject matter of any one of Examples 104 to 106 may optionally include: wherein the thermal pyrolysis process is at a temperature suitable for reducing a molecular size to be equal to or less than a pore size of the catalyst, wherein the temperature is in a range of 150 to 320 °C.

[000124] In Example 108, the subject matter of any one of Examples 104 to 107 may optionally include: wherein the catalytic pyrolysis process is at a temperature in a range of 250 – 370 °C.

20 **[000125]** In Example 109, the subject matter of any one of Examples 104 to 108 may optionally include: further including heating the pyrolysis solid residue via the termination stage to a temperature suitable for breaking down remaining carbon-hydrogen bond and removing remaining hydrogen and moisture from the pyrolysis solid residue, preferably wherein the temperature is at least 350°C.

25 **[000126]** In Example 110, the subject matter of any one of Examples 104 to 109 may optionally include: wherein the proportion of the thermal pyrolysis process and the catalytic pyrolysis process includes a proportion of a retention time of the thermal pyrolysis process and a retention time of the catalytic pyrolysis process.

30 **[000127]** In Example 111, the subject matter of any one of Examples 101 to 110 may optionally include: removing the solid product from a termination stage of the continuous thermal treatment arrangement of the system via a solid product compression unit, wherein the solid product compression unit includes at least two rotatable screws arranged in series from an entrance of the solid product compression unit to an exit of the solid product

compression unit, wherein a direction of solid transfer is from the entrance of the solid product compression unit to the exit of the solid product compression unit.

5 **[000128]** In Example 112, the subject matter of Example 111 may optionally include: wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit to compress the solid product.

10 **[000129]** In Example 113, the subject matter of Example 111 may optionally include: wherein a rotational speed of each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit.

15 **[000130]** Example 114 is a solid compression unit, including at least two rotatable screws arranged in series from an entrance of the solid product compression unit to an exit of the solid product compression unit. The at least two rotatable screws may be cooperatively operable to compress solid materials as the at least two rotatable screws move the solid materials from the entrance of the solid product compression unit to the exit of the solid product compression unit.

20 **[000131]** In Example 115, the subject matter of Example 114 may optionally include: wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the solid compression unit decreases sequentially one after another from the entrance of the solid compression unit to the exit of the solid compression unit so as to be cooperatively operated to compress the solid materials as the solid materials is being moved from the entrance of the solid product compression unit to the exit of the solid product compression unit.

25 **[000132]** In Example 116, the subject matter of Example 115 may optionally include: wherein a rotational speed of each of the at least two rotatable screws of the solid compression unit decreases sequentially one after another from the entrance of the solid compression unit to the exit of the solid compression unit.

30 **[000133]** In Example 117, the subject matter of Example 115 may optionally include: wherein a diameter of a screw shaft of each of the at least two rotatable screws of the solid compression unit increases sequentially one after another from the entrance of the solid compression unit to the exit of the solid compression unit.

[000134] In Example 118, the subject matter of Example 115 may optionally include: wherein a pitch range of each of the at least two rotatable screws of the solid product compression unit decreases sequentially, one rotatable screw after another rotatable screw, from the entrance of the solid product compression unit to the exit of the solid product compression unit.

[000135] In Example 119, the subject matter of any one of Examples 114 to 118 may optionally include: at least three rotatable screws.

[000136] In Example 120, the subject matter of any one of Examples 114 to 119 may optionally include: further including a cooling jacket surrounding at least one rotatable screw.

[000137] FIG. 1A shows a schematic diagram of a system 100 for converting waste plastic materials to useful products according to various embodiments. According to various embodiments, the system 100 may be a pyrolysis system 100. According to various embodiments, the waste plastic materials may include, but not limited to, municipal waste materials which may include various types of polymer, e.g. polypropylene, polyethylene etc. According to various embodiments, the useful product may include, but not limited to, hydrocarbon having carbon atoms in the range of C₂ to C₃₄, such as hydrocarbon that is suitable for petrochemical process or fuel (e.g. Naphtha, Diesel, or other hydrocarbon products), and a solid product. According to various embodiments, the solid product may include, but not limited to, solid carbon (e.g. carbon black), or other solid included in the waste plastic materials etc.

[000138] According to various embodiments, the system 100 may include a waste materials compression unit 200 (or a solid compression unit). According to various embodiments, the waste materials compression unit 200 may receive the waste plastic materials (or waste plastic feed or feedstock). Accordingly, the waste plastic materials may be fed into the waste materials compression unit 200. According to various embodiments, a feeder (not shown) may be connected to the waste materials compression unit 200. The feeder may be for delivering and transporting the waste plastic materials into the waste materials compression unit 200. According to various embodiments, the feeder may include, but not limited to, a volumetric feeder, a gravimetric feeder, a bulk feeder, a linear feeder, a screw feeder, an auger feeder, or a hopper feeder. According to various embodiments, the feeder may be at an opening or entrance of the waste materials compression unit 200. According to various embodiments, the waste materials compression unit 200 may compress

the waste plastic materials to remove air (e.g. oxygen) and moisture from the waste plastic materials to form or generate a compressed waste plastic feed. Accordingly, via compressing or compacting the waste plastic materials, air and moisture in the waste plastic materials may be forced or squeezed out. According to various embodiments, the waste materials compression unit 200 may compress the waste plastic materials at a temperature or temperature range within a range of substantially 90°C to 140°C, preferably 110°C to 120°C. Accordingly, with the waste materials compression unit 200 operating at an elevated temperature, moisture may be evaporated such that the compressed waste plastic feed may be free of moisture. According to various embodiments, the waste materials compression unit 200 may include a heating arrangement including, but not limited to external fire source, electrical heating, heater elements, heating coils, heating pads, etc., to provide heating so as to elevate a temperature within the waste materials compression unit 200. According to various embodiments, the waste materials compression unit 200 may prepare the raw feed/feedstock of the waste plastic materials into a dry and compressed waste plastic feed free of air for subsequent pyrolysis processing. More details of the waste materials compression unit 200 will be described later.

[000139] Referring to FIG. 1A, according to various embodiments, the system 100 may include a thermal treatment arrangement. According to various embodiments, the thermal treatment arrangement may be configured to perform pyrolysis on the compressed waste plastic feed from the waste materials compression unit 200. According to various embodiments, the thermal treatment arrangement may be a continuous thermal treatment arrangement 300. Accordingly, the continuous thermal treatment arrangement 300 may perform pyrolysis in a continuous manner instead of via batch processing. In other words, the waste plastic materials to undergo pyrolysis may be moved or flowed or conveyed or transported continuously through the continuous thermal treatment arrangement 300 for pyrolysis processing rather than processing the materials in batches and moving them batch by batch.

[000140] As shown, the continuous thermal treatment arrangement 300 may be coupled to the waste materials compression unit 200 at a location downstream of the waste materials compression unit 200. Accordingly, the waste materials compression unit 200 may be upstream of the continuous thermal treatment arrangement 300. According to various embodiments, the compressed waste plastic feed may enter or be received in the continuous thermal treatment arrangement 300, from the waste materials compression unit 200, for

melting, pyrolysis and/or heating of the waste plastic feed within the continuous thermal treatment arrangement 300. According to various embodiments, the compressed waste plastic feed may be automatically delivered or transported or conveyed into the continuous thermal treatment arrangement 300. According to various embodiments, the compressed waste plastic feed may also be manually input to the continuous thermal treatment arrangement 300.

[000141] According to various embodiments, the continuous thermal treatment arrangement 300 may include a melting stage 310, a thermal-to-catalytic pyrolysis stage 320, and a termination stage 330 for processing the compressed waste plastic feed via melting, pyrolysis and/or heating. According to various embodiments, the thermal-to-catalytic pyrolysis stage 320 may be positioned or located downstream of the melting stage 310, between the melting stage 310 and the termination stage 330, and the termination stage 330 may be positioned downstream of the thermal-to-catalytic pyrolysis stage 320. Accordingly, the stages of the continuous thermal treatment arrangement 300 may in the order or sequence of the melting stage 310 followed by the thermal-to-catalytic pyrolysis stage 320, which is then followed by the termination stage 330. Hence, the flow or the movement of materials through the continuous thermal treatment arrangement 300 may be in a continuous manner from the melting stage 310 to the thermal-to-catalytic pyrolysis stage 320 and then from the thermal-to-catalytic pyrolysis stage 320 to the termination stage 330.

[000142] According to various embodiments, the melting stage 310 of the continuous thermal treatment arrangement 300 may be configured to melt the compressed waste plastic feed to form a melted mixture or melted plastic mixture. Accordingly, the compressed waste plastic feed passing through the melting stage 310 may be heated to or above a melting temperature. According to various embodiments, the melting stage 310 may heat the compressed waste plastic feed at a temperature or temperature range within a range of substantially 110°C to 160°C, preferably 120°C to 140°C to form the melted mixture in the melting stage 310. According to various embodiments, the melting stage 310 may include a heating arrangement including, but not limited to external fire source, electrical heating, heater elements, heating coils, heating pads, etc., to heat the compressed waste plastic feed.

[000143] According to various embodiments, the melted mixture may be conveyed or transported from the melting stage 310 to the thermal-to-catalytic pyrolysis stage 320 of the continuous thermal treatment arrangement 300

[000144] According to various embodiments, the thermal-to-catalytic pyrolysis stage 320 of the continuous thermal treatment arrangement 300 may subject the melted mixture through a thermal pyrolysis process followed by a catalytic pyrolysis process for producing (or so as to produce) a pyrolysis gas product and/or a pyrolysis solid residue. Accordingly, the thermal-to-catalytic pyrolysis stage 320 may perform pyrolysis in a sequence of the thermal pyrolysis process followed by the catalytic pyrolysis process. According to various embodiments, the thermal-to-catalytic pyrolysis stage 320 may include at least two catalyst feeding points (or a plurality, or two or more catalyst feeding ports 32) distributed along the thermal-to-catalytic pyrolysis stage 320. Accordingly, the at least two catalyst feeding points may be scattered or dispersed or spread along the thermal-to-catalytic pyrolysis stage 320 in a direction of flow or movement of materials along the thermal-to-catalytic pyrolysis stage 320. According to various embodiments, the thermal-to-catalytic pyrolysis stage 320 may be operable to selectively feed or add or input or to receive a catalyst via any one or more of the at least two catalyst feeding points for transforming or switching or changing or converting the thermal pyrolysis process to the catalytic pyrolysis process at different points or positions or locations or juncture along the thermal-to-catalytic pyrolysis stage 320 in a manner so as to vary or adjust or alter a proportion of a proportion of the thermal pyrolysis process and the catalytic pyrolysis process in the thermal-to-catalytic pyrolysis stage 320. According to various embodiments, adding of catalyst to the thermal pyrolysis process may transform or change or switch or convert the thermal pyrolysis process to the catalytic pyrolysis process. Hence, the catalyst may be added or fed or input at a point where catalytic pyrolysis is to take place. Accordingly, when the catalyst is fed or added or input at different catalyst feeding points of the at least two catalyst feeding points, the thermal pyrolysis process may transform or change or switch or covert to the catalytic pyrolysis process at different points or positions or locations or juncture along the thermal-to-catalytic pyrolysis stage 320. Thus, the proportion of the thermal pyrolysis process and the catalytic pyrolysis process in the thermal-to-catalytic pyrolysis stage 320 may be varied or adjusted or altered by feeding or adding or inputting the catalyst at different catalyst feeding points of the at least two catalyst feeding points. According to various embodiments, the proportion of the thermal pyrolysis process and the catalytic pyrolysis process may be a ratio of a duration (or a retention time) of the thermal pyrolysis process to a duration (or a retention time) of the catalytic pyrolysis process in the thermal-to-catalytic pyrolysis stage 320. Accordingly, when a flow rate or a rate of movement through the thermal-to-catalytic pyrolysis stage 320

is constant, the proportion of the thermal pyrolysis process and the catalytic pyrolysis process may be a ratio of a length of the thermal-to-catalytic pyrolysis stage 320 performing the thermal pyrolysis process to a length of the thermal-to-catalytic pyrolysis stage 320 performing the catalytic pyrolysis process.

5 **[000145]** According to various embodiments, by varying a proportion of the thermal pyrolysis process and the catalytic pyrolysis process performed along the thermal-to-catalytic pyrolysis stage 320, a final product 701 generated by the system 100 may be correspondingly changed or altered or varied. Accordingly, depending on the desired final product 701, the proportion of the thermal pyrolysis process and the catalytic pyrolysis process along the thermal-to-catalytic pyrolysis stage 320 may be varied or adjusted or altered so as to perform a processing sequence having the required proportion of the thermal pyrolysis process and the catalytic pyrolysis process to generate the desired final product 701.

15 **[000146]** According to various embodiments, with the at least two (e.g. two or more) catalyst feeding points along the thermal-to-catalytic pyrolysis stage 320 for feeding the catalyst to transform or change or switch or convert the thermal pyrolysis process to the catalytic pyrolysis process at different points or positions or locations or juncture along the thermal-to-catalytic pyrolysis stage 320, the system 100 may be operated to selectively vary a point along the thermal-to-catalytic pyrolysis stage 320 where the catalyst is added to transform or change or switch or convert the thermal pyrolysis process to the catalytic pyrolysis process based on the desired final product 701 to be output from the system 100 or a property of the waste plastic materials or feed that is introduced to the system 100. For example, according to various embodiments, the catalyst may be selectively added in any one or more of the at least two catalyst feeding points of the thermal-to-catalytic pyrolysis stage 320 so as to achieve or attain or realize the proportion of the thermal pyrolysis process and the catalytic pyrolysis process required.

25 **[000147]** As shown in FIG. 1A, according to various embodiments, the thermal-to-catalytic pyrolysis stage 320 may include an initial thermal pyrolysis zone 321, one or more intermediate variable zones 322, and a final catalytic pyrolysis zone 324. According to various embodiments, the initial thermal pyrolysis zone 321, the one or more intermediate variable zones 322, and the final catalytic pyrolysis zone 324 may be arranged in series. Accordingly, the zones of the thermal-to-catalytic pyrolysis stage 320 may be in the order or sequence of the initial thermal pyrolysis zone 321 followed by the one or more

intermediate variable zone 322, and followed by the final catalytic pyrolysis zone 324. According to various embodiments, the one or more intermediate variable zones 322 may be positioned downstream of the initial thermal pyrolysis zone 321, between the initial thermal pyrolysis zone 321 and the final catalytic pyrolysis zone 324, and the final catalytic pyrolysis zone 324 may be positioned downstream of the one or more intermediate variable zones 322. According to various embodiments, the melted mixture of the compressed waste plastic feed may be conveyed or transported along the thermal-to-catalytic pyrolysis stage 320 (e.g. via a conveyor mechanism) from the initial thermal pyrolysis zone 321 towards the final catalytic pyrolysis zone 324, in particular, from the initial thermal pyrolysis zone 321 through the one or more intermediate variable zones 322, and to the final catalytic pyrolysis zone 324. According to various embodiments, the at least two catalyst feeding points may be opened only when the catalyst is to be fed or added to the system 100. For example, each of the at least two catalyst feeding points (e.g. catalyst feeding port) may include a cover that may be opened for feeding the catalyst therein or closed (e.g. to prevent air/gas from entering into or escaping from the catalyst feeding point) According to various embodiments, the at least two catalyst feeding points (e.g. catalyst feeding ports) may include at least one safety valve to prevent air (e.g. from the atmosphere) from entering into system 100 and/or to prevent any gas in the system 100 from leaking or escaping to the atmosphere. According to various embodiments, the catalyst may be fed or added into the system 100 via the at least two catalyst feeding points by at least one catalyst feeder. According to various embodiments, the catalyst feeder may include, but not limited to, a screw feeder, an auger feeder, or a hopper feeder.

[000148] According to various embodiments, the initial thermal pyrolysis zone 321 of the thermal-to-catalytic pyrolysis stage 320 may heat the melted mixture at or above a thermal decomposition temperature of the melted mixture, to break down the molecules of the melted mixture. According to various embodiments, the initial thermal pyrolysis zone 321 may be configured to apply heat to the melted mixture under low oxygen conditions or inert atmospheric conditions to decompose or break down the melted mixture. According to various embodiments, the thermal pyrolysis process may be configured for decomposing or breaking down of the melted mixture into suitable molecule size for the subsequent catalytic pyrolysis process. According to various embodiments, the initial thermal pyrolysis zone 321 may heat the melted mixture at a temperature or temperature range within a range of substantially 130°C to 280°C, preferably 150°C to 250°C. According to various

embodiments, the initial thermal pyrolysis zone 321 may include a heating arrangement including, but not limited to external fire source, electrical heating, heater elements, heating coils, heating pads, etc., to provide heating.

[000149] According to various embodiments, a temperature and/or a duration (i.e. retention time) at which the melted mixture undergoes heating in the initial thermal pyrolysis zone 321 of the thermal-to-catalytic pyrolysis stage 320 may be based on a composition of the melted mixture of the waste plastic materials and/or a type of catalyst to be used for the catalytic pyrolysis process and/or the desired final product 701 (e.g. desired final useful hydrocarbon product or hydrocarbon having carbon atoms in the range of C₂ to C₃₄, such as hydrocarbon that is suitable for petrochemical process or fuel, e.g. Naphtha, Diesel, other hydrocarbon products etc.) to be produced by the system 100. For example, according to various embodiments, the melted mixture in the initial thermal pyrolysis zone 321 may be heated at a temperature and/or a duration which may result in the molecules of the melted mixture being broken down into a suitable (or ideal e.g. smaller) size for entering a pore site (or average diameter of the pores) of the catalyst which may be used (or added) subsequently for the catalytic pyrolysis process.

[000150] According to various embodiments, each of the one or more intermediate variable zones 322 of the thermal-to-catalytic pyrolysis stage 320 may include at least one catalyst feeding port 32, 32a at a start of the intermediate variable zone 322 for receiving the catalyst. According to various embodiments, the at least one catalyst feeding port 32a of each intermediate variable zone 322 may serve as one of the at least two catalyst feeding points along the thermal-to-catalytic pyrolysis stage 320. Accordingly, with more intermediate variable zones 322, the thermal-to-catalytic pyrolysis stage 320 may have more catalyst feeding points for varying the points or positions or locations or juncture along the thermal-to-catalytic pyrolysis stage 320 to add or feed or input the catalyst. According to various embodiments, when the catalyst is added to an intermediate variable zone 322 via the at least one catalyst feeding port 32a at the start of the intermediate variable zone 322, the thermal pyrolysis process may be transformed or changed or switched or converted to the catalytic pyrolysis process in the intermediate variable zone. Accordingly, the remaining zones of the thermal-to-catalytic pyrolysis stage 320 after the intermediate variable zone 322 may perform catalytic pyrolysis process. According to various embodiments, when no catalyst is added or fed or input into an intermediate variable zone 322, the intermediate

variable zone 322 may continue to perform the thermal pyrolysis process similar to the initial thermal pyrolysis zone 321.

[000151] According to various embodiments, in the one or more intermediate variable zones 322, the melted mixture may undergo either a thermal pyrolysis process or a catalytic pyrolysis process depending on whether catalyst is added into the one or more intermediate variable zones 322 (e.g. via the at least one catalyst feeding ports 32a of the one or more intermediate variable zones 322).

[000152] According to various embodiments, the one or more intermediate variable zones 322 may be operated to provide heating at a temperature or temperature range for the thermal pyrolysis process or a temperature or temperature range for the catalytic pyrolysis process. According to various embodiments, depending on whether the catalyst is fed or added or input through the at least one catalyst feeding port 32a of the one or more intermediate variable zone 322, the one or more intermediate variable zone 322 may be heated to the temperature or temperature range for the thermal pyrolysis process or the catalytic pyrolysis process accordingly. According to various embodiments, the one or more intermediate variable zones 322 of the thermal-to-catalytic pyrolysis stage 320 may be heated at a temperature or temperature range within a range of substantially 130°C to 370°C, preferably 150°C to 320°C. For example, according to various embodiments, when no catalyst is fed or added or input via the at least one catalyst feeding ports 32a of the one or more intermediate variable zones 322, the one or more intermediate variable zones 322 may be heated to (or regulated or maintained at) a temperature within a range of substantially 130°C to 280°C, preferably 150°C to 250°C for the thermal pyrolysis process. On the other hand, according to various embodiments, when catalyst is fed or added or input via the at least one catalyst feeding ports 32a of the one or more intermediate variable zones 322, the one or more intermediate variable zones 322 may be heated to (or regulated or maintained at) a temperature or temperature range within a range of substantially 250°C to 370°C, preferably 270°C to 320°C, for catalytic pyrolysis process. According to various embodiments, each of the one or more intermediate variable zones 322 may include a heating arrangement including, but not limited to external fire source, electrical heating, heater elements, heating coils, heating pads, etc., to provide the heating.

[000153] According to various embodiments, the final catalytic pyrolysis zone 324 of the thermal-to-catalytic pyrolysis stage 320 may include at least one catalyst feeding port 32b at a start of the final catalytic pyrolysis zone 324 for receiving the catalyst. According to

various embodiments, the at least one catalyst feeding port 32b of the final catalytic pyrolysis zone 324 may serve as a final catalyst feeding point of the at least two catalyst feeding points along the thermal-to-catalytic pyrolysis stage 320 for receiving the catalyst. According to various embodiments, when no catalyst is fed or added or input to any of the

5 one or more intermediate variable zones 322 (i.e. that is upstream of the final catalytic pyrolysis zone 324) upstream of the final catalytic pyrolysis zone 324, the catalyst may be fed or added or input to the final catalytic pyrolysis zone 324 via its at least one catalyst feeding port 32b. Accordingly, the final catalytic pyrolysis zone 324 may be a final zone of the thermal-to-catalytic pyrolysis stage 320 that may perform the catalytic pyrolysis process.

10 Hence, the final catalytic pyrolysis zone 324 may define a minimum proportion of the thermal-to-catalytic pyrolysis stage 320 for the catalytic pyrolysis process. According to various embodiments, the final catalytic pyrolysis zone 324 may be configured to perform only the catalytic pyrolysis process. For example, according to various embodiments, the final catalytic pyrolysis zone 324 may be operable to provide heating at a temperature or

15 temperature range for the catalytic pyrolysis process. As another example, according to various embodiments, the final catalytic pyrolysis zone 324 may be configured for the catalyst to be fed or added or input via the at least one catalyst feeding port 32b such that the catalytic pyrolysis process always take place at the final catalytic pyrolysis zone 324. According to various embodiments, when no catalyst is fed or added or input to any of the

20 one or more intermediate variable zones 322 (i.e. that is upstream of the final catalytic pyrolysis zone 324), the initial thermal pyrolysis zone 321 and all the one or more intermediate variable zones 322 may perform the thermal pyrolysis process until the catalyst is fed or added or input (e.g. for a first time) via the at least one catalyst feeding port 32b of the final catalytic pyrolysis zone 324 to transform or change or switch or convert the thermal

25 pyrolysis process into the catalytic pyrolysis process in the final catalytic pyrolysis zone 324.

[000154] According to various embodiments, the catalyst may be fed through the at least one catalyst feeding port 32a of the one or more intermediate variable zones 322 and/or the at least one catalyst feeding port 32b of the final catalytic pyrolysis zone 324 for

30 transforming or changing or switching or converting the thermal pyrolysis process to the catalytic pyrolysis process at the different points along the thermal-to-catalytic pyrolysis stage 320. Accordingly, depending on the final product 701 to be output from the system 100, the thermal-to-catalytic pyrolysis stage 320 may be operated to selectively feed or add

or input the catalyst through the at least one catalyst feeding port 32a of the one or more intermediate variable zones 322 and/or the at least one catalyst feeding port 32b of the final catalytic pyrolysis zone 324 so as to vary the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage 320.

5 **[000155]** According to various embodiments, the system 100 may include at least three (or three or more) catalyst feeding ports 32a, 32b. For example, according to various embodiments, the system 100 may include at least two (or two or more) intermediate variable zones 322, whereby the at least two (or two or more) intermediate variable zones 322 may correspondingly include at least two (or two or more) catalyst feeding ports 32a.
10 Further, according to various embodiments, the system 100 may include the final catalytic pyrolysis zone 324 including the at least one catalyst feeding port 32b.

[000156] Accordingly, when there are two intermediate variable zones 322 and the final catalytic pyrolysis zone 324, there may be at least two catalyst feeding ports 32a corresponding to the two intermediate variable zones 322 and one catalyst feeding port 32b
15 corresponding to the final catalytic pyrolysis zone 324. Thus, there may be a total of at least three catalyst feeding ports where the catalyst may be added or fed or input into any one or a combination of the feeding ports 32a, 32b. According to various embodiments, a determination of whether or which of the at least one catalyst feeding ports 32a of the at least one intermediate variable zones 322 and/or the at least one catalyst feeding ports 32b
20 of the final catalytic pyrolysis zone 324 to feed or add or input the catalyst may be based on monitoring a property of the final product 701 output from the system 100 or a property of the waste plastic materials or feed that is introduced to the system 100. According to various embodiments, the point to add the catalyst and the final product 701 output from the system 100 may be dependent on any one or a combination of a composition of the waste plastic
25 materials, the type of catalyst used, or a desired final product 701 from the system 100.

[000157] For example, according to various embodiments, based on a composition of the waste plastic materials and/or an average pore size of the pore sites of the catalyst and/or a property of the final product 701 (e.g. a determined specific gravity), a duration of the thermal pyrolysis process required to decompose or break down the waste plastic materials
30 in order for catalytic pyrolysis process to take place and/or a duration of the catalytic pyrolysis process (or catalytic cracking time) required to generate the desired pyrolysis gas product for achieving the desired final product 701 from the system 100 may be determined. Thus, the required proportion of the thermal pyrolysis process and the catalytic pyrolysis

process within the thermal-to-catalytic pyrolysis stage 320 as well as the point to add the catalyst may be determined. As an example, when the catalyst is fed or added or input in the at least one catalyst feeding ports 32a of the one or more intermediate variable zones 322, the catalytic pyrolysis process may respectively begin in the corresponding intermediate variable zone 322, before reaching the final catalytic pyrolysis zone 324 that is downstream of the corresponding intermediate variable zone 322. Accordingly, adding the catalyst to the corresponding intermediate variable zones 322 via its catalyst feeding port 32a may provide a higher proportion of the catalytic pyrolysis process performed within the thermal-to-catalytic pyrolysis stage 320 as compared to when the catalyst is only added in the final catalytic pyrolysis zone 324.

[000158] As another example, according to various embodiments, different desired final product 701 may require different corresponding retention time of catalytic pyrolysis process. Thus, according to various embodiments, if it is determined that a desired final product 701 requires a longer retention time for catalytic pyrolysis process, the catalyst may be fed or added or input earlier into the system 100. For example, the catalyst may be fed or added or input in the earlier zones (e.g. nearer to the melting stage 310) of the one or more intermediate variable zones 322 to allow (or enable) a longer catalytic pyrolysis process so as to achieve the desired final product 701.

[000159] As yet another example, according to various embodiments, different composition of the waste plastic materials may require different retention time of heating to decompose or break down into a suitable molecule sizes for interacting with the catalyst to be used. Thus, if it is determined that a particular type of waste plastic materials requires a longer retention time for thermal pyrolysis process, then the catalyst may be fed or added or input later. For example, the catalyst may be fed or added or input in the later zones of the one or more intermediate variable zones 322 or the catalyst may be fed or added or input only in the final catalytic pyrolysis zone 324. According to various embodiments, by feeding or adding or inputting the catalyst when the waste plastic materials is sufficiently decomposed or broken down, the effect of the catalyst for the catalytic pyrolysis process may be optimum because all or almost all or most of the catalyst added may be activated to perform its function, with minimal wastage of the catalyst.

[000160] According to various embodiments, the termination stage 330 of the continuous thermal treatment arrangement 300 may be downstream of the thermal-to-catalytic pyrolysis stage 320 and may receive the pyrolysis solid residue from the thermal-to-catalytic pyrolysis

stage 320. According to various embodiments, the termination stage 330 may heat the pyrolysis solid residue (i.e. produced from the thermal-to-catalytic pyrolysis stage 320 of the continuous thermal treatment arrangement 300) for conversion into a solid product (e.g. solid carbon, or other solid included in the waste plastic materials). According to various
 5 embodiments, the termination stage 330 may be heated to and/or at a temperature of at least substantially 350°C (in other words, substantially 350°C or higher). According to various embodiments, the termination stage 330 may include a first heating zone 333 to raise a temperature of the pyrolysis solid residue (e.g. to 350°C or higher from a lower temperature) and a second heating zone 334 to maintain the pyrolysis solid residue at an elevated
 10 temperature. (e.g. at 350°C or higher). According to various embodiments, the termination stage 330 may, among other things, break any remaining carbon-hydrogen (C-H) bonds in the pyrolysis solid residue, remove any hydrogen from the pyrolysis solid residue, and/or dry the pyrolysis solid residue to generate the solid product. According to various embodiments, the termination stage 330 may include a heating arrangement including, but
 15 not limited to external fire source, electrical heating, heater elements, heating coils, heating pads, etc., to provide heating.

[000161] According to various embodiments, the temperature or temperature range of the termination stage 330 may be higher than the temperature or temperature range of the thermal-to-catalytic pyrolysis stage 320. According to various embodiments, the
 20 temperature or temperature range of the thermal-to-catalytic pyrolysis stage 320 may be higher than the temperature or temperature range of the melting stage 310.

[000162] According to various embodiments, the continuous thermal treatment arrangement 300 may include a reactor 350. According to various embodiments, the continuous thermal treatment arrangement 300 may be embodied by the reactor 350.
 25 Accordingly, the reactor 350 may give the continuous thermal treatment arrangement 300 its physical form or shape. According to various embodiments, the reactor 350 may be a single or multi-stage/zone reactor (e.g. six-zone reactor). According to various embodiments, the reactor 350 may include any one or a combination of the melting stage 310, the thermal-to-catalytic pyrolysis stage 320 and the termination stage 330. For example, according to
 30 various embodiments, the reactor 350 may include only the thermal-to-catalytic pyrolysis stage 320. As another example, according to various embodiments, the reactor 350 may include only the melting stage 310 and the thermal-to-catalytic pyrolysis stage 320. As yet another example, according to various embodiments, the reactor 350 may include only the

thermal-to-catalytic pyrolysis stage 320 and the termination stage 330. As a further example, according to various embodiments, the reactor 350 may include all of the melting stage 310, the thermal-to-catalytic pyrolysis stage 320 and the termination stage.

5 **[000163]** According to various embodiments, the reactor 350 may include or may be a cylindrical shaped reactor. Accordingly, the cylindrical shaped reactor may be segmented or partitioned or divided longitudinally (or along its length) into the different stages or zones.

[000164] According to various embodiments, or the continuous thermal treatment arrangement 300 may include a conveyor mechanism 360 to convey or transport the waste plastic materials along the continuous thermal treatment arrangement 300 from the melting stage 310 to through the thermal-to-catalytic pyrolysis stage 320 and to the termination stage 330. Accordingly, according to various embodiments, when the continuous thermal treatment arrangement 300 includes the reactor 350, the reactor 350 may include the conveyor mechanism 360 to convey or transport the waste plastic materials along a longitudinal direction of the reactor 350. Accordingly, the conveyor mechanism 360 may be extending longitudinally along the reactor 350. According to various embodiments, the conveyor mechanism 360 may extend along an entire length of the reactor 350. For example, the conveyor mechanism 360 may convey or transport the waste plastic materials from a front end (or a first longitudinal end) of the reactor 350 towards a rear end (or a second longitudinal end) of the reactor 350. According to various embodiments, the conveyor mechanism 360 of the reactor 350 may include at least one screw conveyor or linear conveyor or belt conveyor or auger conveyor.

25 **[000165]** According to various embodiments, a speed at which the waste plastic materials may be conveyed by the conveyor mechanism along the continuous thermal treatment arrangement 300 (or along the reactor 350) may depend on a desired retention time of the waste plastic materials required.

[000166] According to various embodiments, the reactor 350 may be inclined with respect to a ground 9 or a horizontal plane. For example, according to various embodiments, a rise per run ratio of the reactor 350 may be within a range of: 1:250 to 1:20; 1:200 to 1:50; 1:150 to 1:80 etc.

30 **[000167]** According to various embodiments, the melting stage 310, the thermal-to-catalytic pyrolysis stage 320, and the termination stage 330 may be maintained at the same pressure. Accordingly, according to various embodiments, the melting of compressed waste plastic feed in the melting stage 310, the thermal pyrolysis process and/or the catalytic

pyrolysis process in the thermal-to-catalytic pyrolysis stage 320, and the heating of the pyrolysis solid residue in the termination stage 330 may be performed (or conducted) at the same pressure. According to various embodiments, the reactor 350 may be air tight or hermetically sealed so as to maintain the pressure within the reactor for the melting stage 310, the thermal-to-catalytic pyrolysis stage 320, and/or the termination stage 330. According to various embodiments, the pressure may be within a range of substantially 120 kPa to 180 kPa, preferably 140 kPa to 160 kPa (or 0.2 barg to 0.8 barg, preferably 0.4 barg to 0.6 barg, or 1.2 bar to 1.8 bar, preferably 1.4 bar to 1.6 bar).

[000168] According to various embodiments, the final catalytic pyrolysis zone 324 of the thermal-to-catalytic pyrolysis stage 320 may include at least one pyrolysis gas outlet 326 to release the pyrolysis gas product produced in the thermal-to-catalytic pyrolysis stage 320. Accordingly, when the continuous thermal treatment arrangement 300 includes the reactor 350 that includes at least the thermal-to-catalytic pyrolysis stage 320, the reactor 350 may include the at least one pyrolysis gas outlet 326 at the final catalytic pyrolysis zone 324 within the reactor 350. According to various embodiments, the at least one pyrolysis gas outlet 326 may be an opening or a vent in the reactor 350 at the final catalytic pyrolysis zone 324 of the reactor 350. According to various embodiments, the at least one pyrolysis gas outlet 326 of the final catalytic pyrolysis zone 324 may include a pump 328 operable to draw or remove the pyrolysis gas product out of the final catalytic pyrolysis zone 324. Accordingly, the pump 328 may be connected (e.g. fluidly connected) to the at least one pyrolysis gas outlet 326 of the final catalytic pyrolysis zone 324. According to various embodiments, the pump may include a vacuum pump or a suction pump.

[000169] According to various embodiments, the termination stage 330 of the continuous thermal treatment arrangement 300 may include at least one pyrolysis gas outlet 326 to release the pyrolysis gas product produced in the thermal-to-catalytic pyrolysis stage 320. Accordingly, when the continuous thermal treatment arrangement 300 includes the reactor 350 that includes at least the thermal-to-catalytic pyrolysis stage 320 and the termination stage 330, the reactor 350 may include the at least one pyrolysis gas outlet 326 at the termination stage 330 within the reactor 350. According to various embodiments, the at least one pyrolysis gas outlet 326 may be an opening or a vent in the reactor 350 at the termination stage 330 of the reactor 350. According to various embodiments, the at least one pyrolysis gas outlet 326 of the termination stage 330 may include a pump 328 operable to draw or remove the pyrolysis gas product out of the termination stage 330. Accordingly, the pump

328 may be connected to the at least one pyrolysis gas outlet of the termination stage 330. According to various embodiments, the pump 328 may include a vacuum pump or a suction pump.

[000170] According to various embodiments, the termination stage 330 may include at least one pyrolysis solid outlet 332 for discharging the solid product produced in the termination stage 330 of the thermal-to-catalytic pyrolysis stage 320. Accordingly, when the continuous thermal treatment arrangement 300 includes the reactor 350 that includes at least the thermal-to-catalytic pyrolysis stage 320 and the termination stage 330, the reactor 350 may include the at least one pyrolysis solid outlet 332 at the termination stage 330 within the reactor. According to various embodiments, the at least one pyrolysis solid outlet 332 may be an opening or a passage in the reactor at the termination stage 330 of the reactor 350.

[000171] As shown in FIG. 1A and FIG. 1C, according to various embodiments, the system 100 may include at least one solid product compression unit 400 (or a solid compression unit). The solid product compression unit 400 may be connected (e.g. fluidly connected) to the pyrolysis solid outlet 332 of the termination stage 330 to receive the solid product discharged from the termination stage 330. Accordingly, the solid product compression unit 400 may be positioned downstream of the termination stage 330 of the continuous thermal treatment arrangement 300 for removal of solid product from the continuous thermal treatment arrangement 300. Hence, the solid product compression unit 400 may serve as a solid product removal unit for the continuous thermal treatment arrangement 300. According to various embodiments, the solid product may be removed by the at least one solid product compression unit 400 from the system 100 without shutting down the continuous thermal treatment arrangement 300 because the solid product is compressed at the at least one solid product compression unit 400 in a manner so as to block and prevent air from entering the continuous thermal treatment arrangement 300 through the at least one solid product compression unit 400. According to various embodiments, the solid product compression unit 400 may compress the solid product discharge from the termination stage 330 of the continuous thermal treatment arrangement 300. According to various embodiments, the solid product compression unit 400 may be similar to the waste materials compression unit 200 in terms of the compression mechanism. However, the solid product compression unit 400 may differ from the waste materials compression unit 200 in

that the solid product compression unit 400 may include a cooling arrangement rather than a heating arrangement.

[000172] FIG. 1B shows a schematic diagram of the waste materials compression unit 200 of the system 100 of FIG. 1A according to various embodiments.

5 **[000173]** According to various embodiments, the waste materials compression unit 200 may include at least two (or two or more) rotatable screws. For example, the waste materials compression unit 200 may include at least a first rotatable screw 203a and at least a second rotatable screw 203b. As another example, the waste materials compression unit 200 may further include a third rotatable screw 203c. According to various embodiments, including
10 the third screw 203c in the waste materials compression unit 200 may enable the waste materials compression unit 200 to compress the waste plastic materials to a higher extent or compression ratio, thereby resulting in better prevention of air (e.g. from the atmosphere) from entering into system 100 and/or better prevention of any gas in the system 100 from leaking or escaping to the atmosphere. As a further example, the waste materials
15 compression unit 200 may include one or more other additional rotatable screws.

[000174] According to various embodiments, the at least two rotatable screws 203 of the waste materials compression unit 200 may be arranged in series. For example, the first rotatable screw 203a of the waste materials compression unit 200, the second rotatable screw 203b of the waste materials compression unit 200, and the third rotatable screw 203c of the
20 waste materials compression unit 200 may be arranged in series. Accordingly, the at least two rotatable screws 203 of the waste materials compression unit 200 may be arranged in sequence one after another from an entrance 201 (or leading end) of the waste materials compression unit 200 to an exit 202 (or trailing end) of the waste materials compression unit 200. According to various embodiments, the at least two rotatable screws 203 of the waste
25 materials compression unit 200 may be lined in sequence with an end of one rotatable screw directed or pointed to an end of an adjacent subsequent rotatable screw. According to various embodiments, the at least two rotatable screws 203 may in an end-to-end arrangement wherein the end of one rotatable screw is abutting or in contact or touching the end of the adjacent subsequent rotatable screw. According to various embodiments, the at
30 least two rotatable screws 203 may be in a spaced-ends arrangement wherein the end of one rotatable screw is spaced from the end of the adjacent subsequent rotatable screw with a gap or an intervening space therebetween. According to various embodiments, the at least two rotatable screws 203 of the waste materials compression unit 200 may be arranged in order

between the entrance 201 and the exit 202 of the waste materials compression unit 200. According to various embodiments, a direction of solid transfer of the waste materials compression unit 200 may be from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. Accordingly, the direction of solid transfer may be along the at least two rotatable screws 203 of the waste materials compression unit 200 in a successive manner from a rotatable screw immediately adjacent to the entrance 201 of the waste materials compression unit 200 to a rotatable screw immediately adjacent to the exit 202 of the waste materials compression unit 200.

[000175] According to various embodiments, the waste materials compression unit 200 may be configured such that a volumetric rate of flow generated by each of the at least two rotatable screws 203 of the waste materials compression unit 200 decreases sequentially one after another from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. Accordingly, the volumetric rate of flow of each successive rotatable screw of the at least two rotatable screws 203 of the waste materials compression unit 200 may be lower than that of a corresponding preceding rotatable screw. Hence, due to the decrease in the volumetric rate of flow generated by each of the at least two rotatable screws 203 of the waste materials compression unit 200 as compared to that of the preceding rotatable screw, the waste plastic materials may be compressed into the compressed waste plastic feed as the waste plastic materials move from the entrance 201 to the exit 202 of the waste materials compression unit 200. Thus, by way of decreasing the volumetric rate of flow of the at least two screws 203 arranged in series from the entrance 201 to the exit 202 of the waste materials compression unit 200, the waste plastic materials fed into the waste materials compression unit 200 may move at different volumetric rate of flow along different segments of the waste materials compression unit 200, whereby the volumetric rate of flow between the different segments are decreasing from the entrance 201 to the exit 202 of the waste materials compression unit 200. Accordingly, the waste plastic materials from a preceding segment with a higher volumetric rate of flow may collide with a subsequent segment with a lower volumetric rate of flow to compress the waste plastic materials due to the change in the volumetric rate of flow. According to various embodiments, the waste plastic materials in the waste materials compression unit 200 may be compressed or compacted to remove air and/or moisture, to prevent air (e.g. from the atmosphere) from entering into system 100 and/or prevent any gas in the system 100 from leaking or escaping to the atmosphere.

[000176] According to various embodiments, the waste materials compression unit 200 may be connected directly to the melting stage 310 of the continuous thermal treatment arrangement 300. According to various embodiments, the exit 202 of the waste materials compression unit 200 may be connected to the melting stage 310. Accordingly, the waste plastic materials that is fed into the waste materials compression unit 200 may be conveyed along the waste materials compression unit 200 by the at least two rotatable screws 203 arrange in series. For example, the waste plastic materials may be fed into the waste materials compression unit 200 at a first end of the first rotatable screw 203a and move through (or along) the waste materials compression unit 200 via the first rotatable screw 203a followed by successive rotatable screw one after another (e.g. followed by the second rotatable screw 203b, etc.) and then be fed into the melting stage 310 of the continuous thermal treatment arrangement 300.

[000177] According to various embodiments, the waste materials compression unit 200 may be operable such that a rotational speed of each of the at least two rotatable screws 203 of the waste materials compression unit 200 decreases sequentially one after another from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. Accordingly, a rotational speed of each successive rotatable screw of the at least two rotatable screws 203 of the waste materials compression unit 200 may be slower than a rotational speed of a corresponding preceding rotatable screw. For example, the second rotatable screw 203b of the waste materials compression unit 200 may have a rotation speed of 40% to 100%, or 55% to 98%, or 70% to 97%, or 80% to 95% of that of the first rotatable screw 203a of the waste materials compression unit 200, and the third rotatable screw 203c of the waste materials compression unit 200 may have a rotational speed of 35% to 97%, or 40% to 95%, or 50% to 90%, or 60% to 88%, or 70% to 85% of that of the first rotatable screw 203a of the waste materials compression unit 200. Hence, due to the decrease in the rotational speed of each of the at least two rotatable screws 203 of the waste materials compression unit 200 as compared to that of the preceding rotatable screw, the volumetric rate of flow generated by each of the at least two rotatable screws 203 of the waste materials compression unit 200 may decrease sequentially one after another from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. According to various embodiments, the at least two rotatable screws 203 of the waste materials compression unit 200 may be of a same size and/or dimension. For example, a screw shaft diameter, a screw blade diameter, and a pitch

of the at least two rotatable screws 203 of the waste materials compression unit 200 may be the same.

[000178] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a, the second rotatable screw 203b and the third rotatable screw 203c, two of the three rotatable screws 203a, 203b, 203c may have a same rotation speed. For example, according to various embodiments, both the first rotatable screw 203a and the second rotatable screw 203b may have the same rotation speed, while the third rotatable screw 203c may have a slower rotation speed relative to both the first rotatable screw 203a and the second rotatable screw 203b. As yet another example, according to various embodiments, both the second rotatable screw 203b and the third rotatable screw 203c may have a same rotation speed, while the first rotatable screw 203a may have a faster rotation speed relative to both the second rotatable screw 203b and the third rotatable screw 203c.

[000179] According to various embodiments, a diameter of a screw shaft of each of the at least two rotatable screws 203 of the waste materials compression unit 200 may increase sequentially one after another from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. Accordingly, a diameter of a screw shaft of each successive rotatable screw of the at least two rotatable screws 203 of the waste materials compression unit 200 may be larger than a diameter of a screw shaft of a corresponding preceding rotatable screw. For example, a diameter of a screw shaft of the first rotatable screw 203a may be smaller than a diameter of a screw shaft of the second rotatable screw 203b, and the screw shaft of the second rotatable screw 203b may be smaller than a diameter of a screw shaft of the third rotatable screw 203c. Hence, due to the increase in the diameter of the screw shaft of each of the at least two rotatable screws 203 of the waste materials compression unit 200 as compared to that of the preceding rotatable screw, a volume of space for solid transfer may decrease from one rotatable screw to a next. Thus, the volumetric rate of flow generated by each of the at least two rotatable screws 203 of the waste materials compression unit 200 may decrease sequentially one after another from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. According to various embodiments, the at least two rotatable screws 203 of the waste materials compression unit 200 may be rotating at the same or different rotational speed, preferably the same rotation speed.

[000180] According to various embodiments, a pitch (or pitch range) of each of the at least two rotatable screws 203 of the waste materials compression unit 200 may decrease sequentially, one rotatable screw after another rotatable screw, from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. For example, a pitch range of the first rotatable screw 203a may be larger than a pitch range of the second rotatable screw 203b, and the pitch range of the second rotatable screw 203b may be larger than a pitch range of the third rotatable screw 203c. Accordingly, a pitch of each successive rotatable screw of the at least two rotatable screws 203 of the waste materials compression unit 200 may be narrower than a pitch of a corresponding preceding rotatable screw. Hence, due to the decrease in the pitch of each of the at least two rotatable screws 203 of the waste materials compression unit 200 as compared to that of the preceding rotatable screw, the volumetric rate of flow generated by each of the at least two rotatable screws 203 of the waste materials compression unit 200 may decrease sequentially one after another from the entrance 201 of the waste materials compression unit 200 to the exit 202 of the waste materials compression unit 200. According to various embodiments, the at least two rotatable screws 203 of the waste materials compression unit 200 may be rotating at the same or different rotational speed, preferably the same rotation speed, and may have a same screw shaft diameter and a same screw blade diameter.

[000181] According to various embodiments, at least one rotatable screw of the at least two rotatable screws 203 of the waste materials compression unit 200 may be inclined or oriented to slant upwardly with respect to the ground 9 or the horizontal plane in a manner such that any liquid or moisture may be drained downward via gravity. Accordingly, the inclination of the at least one rotatable screw of the at least two rotatable screws 203 may facilitate removal of the moisture from the waste plastic materials. For example, as shown in FIG. 1B, a first rotatable screw 203a may be vertically positioned, the second rotatable screw 203b may be inclined, while the third rotatable screw 203c may be horizontally positioned (e.g. to facilitate feeding of the waste plastic material into the continuous thermal treatment arrangement 300).

[000182] FIG. 1C shows a schematic diagram of the solid product compression unit 400 of the system 100 of FIG. 1A according to various embodiments.

[000183] According to various embodiments, the solid product compression unit 400 may, similar to the waste materials compression unit 200, include at least two (or two or more) rotatable screws. For example, the solid product compression unit 400 may include at least

a first rotatable screw 403a and at least a second rotatable screw 403b. As another example, the solid product compression unit 400 may further include a third rotatable screw 403c. According to various embodiments, including the third screw 403c in the solid product compression unit 400 may enable the solid product compression unit 400 to compress the solid product or solid materials to a higher extent or compression ratio, thereby resulting in better prevention of air (e.g. from the atmosphere) from entering into system 100 and/or better prevention of any gas in the system 100 from leaking or escaping to the atmosphere. As a further example, the solid product compression unit 400 may include one or more other additional rotatable screws.

10 **[000184]** According to various embodiments, the at least two rotatable screws 403 of the solid product compression unit 400 may, similar to that of the waste materials compression unit 200, be arranged in series. For example, the first rotatable screw 403a of the solid product compression unit 400, the second rotatable screw 403b of the solid product compression unit 400, and the third rotatable screw 403c of the solid product compression unit 400 may be arranged in series. Accordingly, the at least two rotatable screws 403 of the solid product compression unit 400 may be arranged in sequence one after another from an entrance 401 (or leading end) of the solid product compression unit 400 to an exit 402 (or trailing end) of the solid product compression unit 400. According to various embodiments, the at least two rotatable screws 403 of the solid product compression unit 400 may be lined in sequence with an end of one rotatable screw directed or pointed to an end of an adjacent subsequent rotatable screw. According to various embodiments, the at least two rotatable screws 403 may in an end-to-end arrangement wherein the end of one rotatable screw is abutting or in contact or touching the end of the adjacent subsequent rotatable screw. According to various embodiments, the at least two rotatable screws 403 may be in a spaced-ends arrangement wherein the end of one rotatable screw is spaced from the end of the adjacent subsequent rotatable screw with a gap or an intervening space therebetween. According to various embodiments, the at least two rotatable screws 403 of the solid product compression unit 400 may be arranged in order between the entrance 401 and the exit 402 of the solid product compression unit 400. According to various embodiments, a direction of solid transfer of the solid product compression unit 400 may be from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. Accordingly, the direction of solid transfer may be along the at least two rotatable screws 403 of the solid product compression unit 400 in a successive manner from a

rotatable screw immediately adjacent to the entrance 401 of the solid product compression unit 400 to a rotatable screw immediately adjacent to the exit 402 of the solid product compression unit 400.

[000185] According to various embodiments, the solid product compression unit 400 may, similar to the waste materials compression unit 200, be configured such that a volumetric rate of flow generated by each of the at least two rotatable screws 403 of the solid product compression unit 400 decreases sequentially one after another from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. Accordingly, the volumetric rate of flow of each successive rotatable screw of the at least two rotatable screws 403 of the solid product compression unit 400 may be lower than that of a corresponding preceding rotatable screw. Hence, due to the decrease in the volumetric rate of flow generated by each of the at least two rotatable screws 403 of the solid product compression unit 400 as compared to that of the preceding rotatable screw, the solid product may be compressed as the solid product move from the entrance 401 to the exit 402 of the solid product compression unit 400. Thus, by way of decreasing the volumetric rate of flow of the at least two screws arranged in series from the entrance 401 to the exit 402 of the solid product compression unit 400, solid product fed into the solid product compression unit 400 may move at different volumetric rate of flow along different segments of the waste materials compression unit 200, whereby the volumetric rate of flow between the different segments are decreasing from the entrance 401 to the exit 402 of the solid product compression unit 400. Accordingly, the solid product from a preceding segment with a higher volumetric rate of flow may collide with a subsequent segment with a lower volumetric rate of flow to compress the solid product due to the change in the volumetric rate of flow. According to various embodiments, the solid product in the solid product compression unit 400 may be compressed or compacted to prevent air (e.g. from the atmosphere) from entering into the system 100 and/or prevent any gas in the system 100 from leaking or escaping to the atmosphere while operating.

[000186] According to various embodiments, the solid product compression unit 400 may be connected directly to the termination stage 330 of the continuous thermal treatment arrangement 300. According to various embodiments, the entrance 401 of the solid product compression unit 400 may be connected to the pyrolysis solid outlet 332 of the termination stage 330. Accordingly, the solid product from the termination stage 330 may be fed into the solid product compression unit 400 and may be conveyed along the solid product

compression unit 400 by the at least two rotatable screws 403 arrange in series. For example, the solid product may be fed into the solid product compression unit 400 at a first end of the first rotatable screw 403a and move through (or along) the solid product compression unit 400 via the first rotatable screw 403a followed by successive rotatable screw one after another (e.g. followed by the second rotatable screw 403b, etc.).

[000187] According to various embodiments, the solid product compression unit 400 may, similar to the waste materials compression unit 200, be operable such that a rotational speed of each of the at least two rotatable screws 403 of the solid product compression unit 400 decreases sequentially one after another from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. Accordingly, a rotational speed of each successive rotatable screw of the at least two rotatable screws 403 of the solid product compression unit 400 may be slower than a rotational speed of a corresponding preceding rotatable screw. For example, the second rotatable screw 403b of the solid product compression unit 400 may have a rotation speed of 40% to 100%, or 55% to 98%, or 70% to 97%, or 80 to 95% of that of the first rotatable screw 403a of the solid product compression unit 400, and the third rotatable screw 403c of the solid product compression unit 400 may have a rotation speed of 35% to 97%, or 40% to 95%, or 50% to 90%, or 60 to 88%, or 70% to 85% of that of the first rotatable screw 403a of the solid product compression unit 400. Hence, due to the decrease in the rotational speed of each of the at least two rotatable screws 403 of the solid product compression unit 400 as compared to that of the preceding rotatable screw, the volumetric rate of flow generated by each of the at least two rotatable screws 403 of the solid product compression unit 400 may decrease sequentially one after another from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. According to various embodiments, the at least two rotatable screws 403 of the solid product compression unit 400 may be of a same or different size and/or dimension. For example, a screw shaft diameter, a screw blade diameter, and a pitch of the at least two rotatable screws 403 of the solid product compression unit 400 may be the same.

[000188] According to various embodiments, similar to that of the waste materials compression unit 200, when the solid product compression unit 400 includes the first rotatable screw 403a, the second rotatable screw 403b and the third rotatable screw 403c, two of the three rotatable screws 403 may have a same rotation speed. For example, according to various embodiments, both the first rotatable screw 403a and the second

rotatable screw 403b may have the same rotation speed, while the third rotatable screw 403c may have a slower rotation speed relative to both the first rotatable screw 403a and the second rotatable screw 403b. As yet another example, according to various embodiments, the second rotatable screw 403b and the third rotatable screw 403c may have a same rotation speed, while the first rotatable screw 403a may have a faster rotation speed than both the second rotatable screw 403b and the third rotatable screw 403c.

[000189] According to various embodiments, a diameter of a screw shaft of each of the at least two rotatable screws 403 of the solid product compression unit 400 may, similar to that of the waste materials compression unit 200, increase sequentially one after another from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. Accordingly, a diameter of a screw shaft of each successive rotatable screw of the at least two rotatable screws 403 of the solid product compression unit 400 may be larger than a diameter of a screw shaft of a corresponding preceding rotatable screw. For example, a diameter of a screw shaft of the first rotatable screw 403a may be smaller than a diameter of a screw shaft of the second rotatable screw 403b, and the screw shaft of the second rotatable screw 403b may be smaller than a diameter of a screw shaft of the third rotatable screw 403c. Hence, due to the increase in the diameter of the screw shaft of each of the at least two rotatable screws 403 of the solid product compression unit 400 as compared to that of the preceding rotatable screw, a volume of space and/or volumetric rate of flow for solid transfer may decrease from one rotatable screw to a next. Thus, the volumetric rate of flow generated by each of the at least two rotatable screws 403 of the solid product compression unit 400 may decrease sequentially one after another from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. According to various embodiments, the at least two rotatable screws 403 of the solid product compression unit 400 may be rotating at the same or different rotational speed, preferably the same rotation speed.

[000190] According to various embodiments, a pitch (or pitch range) of each of the at least two rotatable screws 403 of the solid product compression unit 400 may, similar to that of the waste materials compression unit 200, decrease sequentially, one rotatable screw after another rotatable screw, from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. Accordingly, a pitch of each successive rotatable screw of the at least two rotatable screws 403 of the solid product compression unit 400 may be narrower than a pitch of a corresponding preceding rotatable

screw. For example, a pitch range of the first rotatable screw 403a may be larger than a pitch range of the second rotatable screw 403b, and the pitch range of the second rotatable screw 403b may be larger than a pitch range of the third rotatable screw 403c. Hence, due to the decrease in the pitch of each of the at least two rotatable screws 403 of the solid product compression unit 400 as compared to that of the preceding rotatable screw, the volumetric rate of flow generated by each of the at least two rotatable screws 403 of the solid product compression unit 400 may decrease sequentially one after another from the entrance 401 of the solid product compression unit 400 to the exit 402 of the solid product compression unit 400. According to various embodiments, the at least two rotatable screws 403 of the solid product compression unit 400 may be rotating at the same or different rotational speed, preferably the same rotation speed, and may have a same screw shaft diameter and a same screw blade diameter.

[000191] According to various embodiments, at least one rotatable screw of the at least two rotatable screws 403 of the solid product compression unit 400 may, similar to the waste materials compression unit 200, be inclined or oriented to slant upwardly with respect to the ground 9 or the horizontal plane such that any solid product and/or liquid in the continuous thermal treatment arrangement 300 may be unable to escape unintendedly from the exit 402 of the solid product compression unit 400. For example, as shown in FIG. 1C, according to various embodiments, a first rotatable screw 403a may be positioned vertically below the termination stage 330, the second rotatable screw 403b may be positioned horizontally, and the third rotatable screw 403c may be inclined with respect to ground 9, such that any solid product or liquid or combination thereof that falls down the first rotatable screw 403a may be collected along the second rotatable screw 403b while being prevented from unintended discharge via the third rotatable screw 403c.

[000192] According to various embodiments, the solid product compression unit 400 may include a cooling jacket 470 surrounding at least one rotatable screw of the at least two rotatable screws 403 of the solid product compression unit 400. According to various embodiments, the cooling jacket 470 may serve as the cooling arrangement of the solid product compression unit 400. According to various embodiments, a cooling fluid (e.g. a refrigerant) may be circulated through and/or around the cooling jacket 470 to cool the solid product (e.g. moving along and/or being compressed) in the solid product compression unit 400.

[000193] Referring to FIG. 1B and FIG. 1C, while the waste materials compression unit 200 and the solid product compression unit 400 are similar in that both serve to compress solids, the solids that is to be compressed by each of the waste materials compression unit 200 and the solid product compression unit 400 may be different. For example, the waste materials compression unit 200 serve to compress waste plastic materials and the solid product compression unit 400 serve to compress solid product from the continuous thermal treatment arrangement 300. Accordingly, the waste materials compression unit 200 and the solid product compression unit 400 may be configured differently for compressing different solids even though they serve similar functions.

[000194] According to various embodiments, in the waste materials compression unit 200, the second rotatable screw 203b may have a rotation speed of 40% to 100%, or 55% to 98%, or 70% to 97%, or 80% to 95% of that of the first rotatable screw 203a.

[000195] According to various embodiments, in the solid product compression unit 400, the second rotatable screw 403b may have a rotation speed of 40% to 100%, or 55% to 98%, or 70% to 97%, or 80% to 95% of the rotation speed of the first rotatable screw 403a.

[000196] According to various embodiments, in the waste materials compression unit 200, the third rotatable screw 203c may have a rotation speed of 35% to 97%, or 40 to 95%, or 50% to 90%, or 60% to 88% or 70% to 85% of that of the first rotatable screw 203a.

[000197] According to various embodiments, in the solid product compression unit 400, the third rotatable screw 403c may have a rotation speed of 35% to 97%, or 40 to 95%, or 50% to 90%, or 60% to 88% or 70% to 85% of that of the first rotatable screw 403a.

[000198] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a, and the second rotatable screw 203b, a shaft diameter of the first rotatable screw 203a may be smaller than a shaft diameter of the second rotatable screw 203b. For example, the shaft diameter of the second rotatable screw 203b may be 100% to 135%, or 105% to 130% of that of the first rotatable screw 203a.

[000199] According to various embodiments, when the solid product compression unit 400 includes the first rotatable screw 203a, 403a and the second rotatable screw 403b, a shaft diameter of the first rotatable screw 403a may be smaller than a shaft diameter of the second rotatable screw 403b. For example, the shaft diameter of the second rotatable screw 403b may be 100% to 135%, or 105% to 130% of that of the first rotatable screw 403a.

[000200] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a, the second rotatable screw 203b and the third

rotatable screw 203c, the shaft diameter of the first rotatable screw 203a may be the same or smaller, preferably smaller than the second rotatable screw 203b and the shaft diameter of the second rotatable screw 203b may be the same or smaller than the shaft diameter of the third rotatable screw 203c. For example, according to various embodiments, the shaft
 5 diameter of the second rotatable screw 203b, 403b may be 100% to 135%, or 105% to 130% of that of the first rotatable screw 203a, 403a and the shaft diameter of the third rotatable screw 203c, 403c may be 105% to 155%, or 108% to 145% of that of the first rotatable screw 203a, 403a.

[000201] According to various embodiments, when the solid product compression unit
 10 400 includes the first rotatable screw 403a, the second rotatable screw 403b and the third rotatable screw 403c, the shaft diameter of the first rotatable screw 403a may be the same or smaller, preferably smaller than the second rotatable screw 403b and the shaft diameter of the second rotatable screw 403b may be the same or smaller than the shaft diameter of the third rotatable screw 403c. For example, according to various embodiments, the shaft
 15 diameter of the second rotatable screw 403b may be 100% to 135%, or 105% to 130% of that of the first rotatable screw 403a and the shaft diameter of the third rotatable screw 403c may be 105% to 155%, or 108% to 145% of that of the first rotatable screw 403a.

[000202] According to various embodiments, when the waste materials compression unit
 200 includes the first rotatable screw 203a, the second rotatable screw 203b, and the third
 20 rotatable screw 203c, the shaft diameter of the first rotatable screw 203a, may be the same as the second rotatable screw 203b, and the shaft diameter of the second rotatable screw 203b may be smaller than the shaft diameter of the third rotatable screw 203c.

[000203] According to various embodiments, when the solid product compression unit
 400 includes the first rotatable screw 403a, the second rotatable screw 403b and the third
 25 rotatable screw 403c, the shaft diameter of the first rotatable screw 403a may be the same as the second rotatable screw 403b and the shaft diameter of the second rotatable screw 403b may be smaller than the shaft diameter of the third rotatable screw 403c.

[000204] According to various embodiments, when the waste materials compression unit
 200 includes the first rotatable screw 203a and the second rotatable screw 203b, the first
 30 rotatable screw 203a and the second rotatable screw 203b may have a same pitch range. For example, according to various embodiments, the first rotatable screw 203a and the second rotatable screw 203b may have a pitch range of within substantially 70 mm to 220 mm, or 80 mm to 200 mm.

[000205] According to various embodiments, when the solid product compression unit 400 includes the first rotatable screw 403a and the second rotatable screw 403b, the first rotatable screw 403a and the second rotatable screw 403b may have a same pitch range. For example, according to various embodiments, the first rotatable screw 403a and the second
 5 rotatable screw 403b may have a pitch range of within substantially 70 mm to 220 mm, or 80 mm to 200 mm.

[000206] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a, the second rotatable screw 203b, and the third rotatable screw 203c, all of the first rotatable screw 203a, the second rotatable screw 203b,
 10 and the third rotatable screw 203c, may have a same pitch range. For example, according to various embodiments, the first rotatable screw 203a, the second rotatable screw 203b, and the third rotatable screw 203c, may have a pitch range of within substantially 70 mm to 220 mm, or 80 mm to 200 mm.

[000207] According to various embodiments, when the solid product compression unit 400 includes the first rotatable screw 403a, the second rotatable screw 403b and the third rotatable screw 403c, all of the first rotatable screw 403a, the second rotatable screw 403b
 15 and the third rotatable screw 403c may have a same pitch range. For example, according to various embodiments, the first rotatable screw 403a, the second rotatable screw 403b and the third rotatable screw 403c may have a pitch range of within substantially 70 mm to 220
 20 mm, or 80 mm to 200 mm.

[000208] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a and the second rotatable screw 203b, a pitch range of the first rotatable screw 203a may be larger than a pitch range of the second rotatable screw 203b. For example, according to various embodiments, the pitch range of
 25 the second rotatable screw 203b may be within substantially 70% to 100%, or 75% to 99%, or 78% to 98% of that of the first rotatable screw 203a.

[000209] According to various embodiments, when the solid product compression unit 400 includes the first rotatable screw 403a and the second rotatable screw 403b, a pitch range of the first rotatable screw 403a may be larger than a pitch range of the second
 30 rotatable screw 403b. For example, according to various embodiments, the pitch range of the second rotatable screw 403b may be within substantially 70% to 100%, or 75% to 99%, or 78% to 98% of the pitch range of the first rotatable screw 403a.

[000210] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a, the second rotatable screw 203b and the third rotatable screw 203c, the pitch range of the first rotatable screw 203a, may be the same or larger, preferably larger than the pitch range of the second rotatable screw 203b, and the pitch range of the second rotatable screw 203b, may be the same or larger than the pitch range of the third rotatable screw 203c. For example, according to various embodiments, the pitch range of the second rotatable screw 203b may be within substantially 70% to 100%, or 75% to 99%, or 78% to 98% of that of the first rotatable screw 203a and the pitch range of the third rotatable screw 203c may be within substantially 65% to 98%, or 75% to 95%, or 80% to 93% of that of the first rotatable screw 203a.

[000211] According to various embodiments, when the solid product compression unit 400 includes the first rotatable screw 403a, the second rotatable screw 403b and the third rotatable screw 403c, the pitch range of the first rotatable screw 403a may be the same or larger, preferably larger than the pitch range of the second rotatable screw 403b and the pitch range of the second rotatable screw 403b may be the same or larger than the pitch range of the third rotatable screw 403c. For example, according to various embodiments, the pitch range of the second rotatable screw 403b may be within substantially 70% to 100%, or 75% to 99%, or 78% to 98% of that of the first rotatable screw 403a and the pitch range of the third rotatable screw 203c, 403c may be within substantially 65% to 98%, or 75% to 95%, or 80% to 93% of that of the first rotatable screw 403a.

[000212] According to various embodiments, when the waste materials compression unit 200 includes the first rotatable screw 203a, the second rotatable screw 203b and the third rotatable screw 203c, the pitch range of the first rotatable screw 203a may be the same as the pitch range of the second rotatable screw 203b and the pitch range of the second rotatable screw 203b may be larger than the pitch range of the third rotatable screw 203c.

[000213] According to various embodiments, when the solid product compression unit 400 includes the first rotatable screw 403a, the second rotatable screw 403b and the third rotatable screw 403c, the pitch range of the first rotatable screw 403a may be the same as the pitch range of the second rotatable screw 403b and the pitch range of the second rotatable screw 403b may be larger than the pitch range of the third rotatable screw 403c.

[000214] According to various embodiments, the solid product compression unit 400 may reduce (or may be configured to reduce) a bulk density of the solid product (i.e. passing along and/or being compressed in the solid product compression unit 400) such that the solid

product may have a bulk density in a range of substantially 1.0 to 3.0 g/cm³, preferably 1.4 to 2.2 g/cm³. According to various embodiments, the solid product may have a compression ratio in a range of substantially 2.0 to 6.0.

[000215] According to various embodiments, a particle size (or average particle size) of the solid product leaving the solid product compression unit 400 may be dependent on a particle size of sand and stone in the waste plastic materials. According to various embodiments, the particle size (or average particle size) of the solid product leaving the solid product compression unit 400 may be within a range of substantially 30 nm to 500 nm.

[000216] Referring back to FIG. 1A, according to various embodiments, the system may include at least one heat exchanger units 500 connected (e.g. fluidly connected) to the at least one pyrolysis gas outlet 326 of the final catalytic pyrolysis zone 324 or the termination stage 330. According to various embodiments, the at least one heat exchanger units 500 may subject the pyrolysis gas product through a heat transfer process as the pyrolysis gas product pass into the at least one heat exchanger units 500 from the continuous thermal treatment arrangement 300 (e.g. thermal-to-catalytic pyrolysis stage 320 and/or termination stage 330). For example, according to various embodiments, the at least one heat exchanger units 500 may condense some long chain carbon compounds of the pyrolysis gas product which are undesired or not required for subsequent processing to generate the useful product or the final product 701. These condensed long chain carbon compounds may be directed or flow back into the thermal-to-catalytic pyrolysis stage 320, for example, via gravity as recycled wax, for further cracking in the thermal-to-catalytic pyrolysis stage 320. According to the various embodiment, the long chain carbon compounds may include, but not limited to, a compound having a carbon chain longer than a carbon chain of the desired product (e.g. Naphtha or Diesel)

[000217] Accordingly to various embodiments, the at least one heat exchanger units 500 may be configured to minimize pressure drop in the continuous thermal treatment arrangement 300. According to various embodiments, the at least one heat exchanger units 500 may include any suitable type of heat exchanger units 500. For example, according to various embodiments, the at least one heat exchanger units 500 may include a shell-and tube heat exchanger or a double-pipe heat exchanger (e.g. a gravity type double-pipe heat exchanger), whereby a cooling fluid, such as a refrigerant having a temperature lower than the temperature of the final catalytic pyrolysis zone 324, may flow or pass through an outer pipe of the double-pipe heat exchanger while the hotter pyrolysis gas product produced from

the continuous thermal treatment arrangement 300 (e.g. the melting stage and/or the thermal-to-catalytic pyrolysis stage 320 and/or the termination stage 330) may flow or pass through an inner pipe or pipes of the double-pipe heat exchanger surrounded by the outer pipe. According to various embodiments, the double-pipe heat exchanger is preferred.

5 **[000218]** As shown in FIG. 1A, according to various embodiments, the system 100 may include at least one gas separator unit 600 downstream of the at least one heat exchanger units 500. According to various embodiments, the at least one gas separator unit 600 may be in fluid communication with the at least one heat exchanger units 500. According to various embodiments, the at least one gas separator unit 600 may remove residue particulate
10 or heavy hydrocarbon or a combination thereof from the pyrolysis gas product, which may be produced in the continuous thermal treatment arrangement 300 (e.g. the melting stage 310 and/or the thermal-to-catalytic pyrolysis stage 320 and/or the termination stage 330) and which may be passed through the at least one heat exchanger units 500. The residue particulate removed by the at least one gas separator unit 600 may include solid particles,
15 charred particles etc.

[000219] According to various embodiments, the at least one gas separator unit 600 may include any suitable type of gas separator unit 600. For example, according to various embodiments, the at least one gas separator unit 600 may include a cyclone separator or a drum separator where cyclone separator is preferred. Accordingly, the pyrolysis gas product
20 which enters the cyclone separator, according to various embodiments, may undergo vortex separation.

[000220] According to various embodiments, the at least one gas separator unit 600 may be further connected (e.g. fluidly connected) to the thermal-to-catalytic pyrolysis stage 320, such as to the initial thermal pyrolysis zone 321 of the thermal-to-catalytic pyrolysis stage
25 320, in a manner such that the residue particulate and the heavy hydrocarbon removed by the at least one gas separator unit 600 may be directed or re-entered into the thermal-to-catalytic pyrolysis stage 320, for example, for further melting, heating and/or pyrolysis.

[000221] According to various embodiments, before entering the at least one gas separator unit 600, the pyrolysis gas product may enter or pass through or be processed by other
30 equipment, such as distillation column(s) interconnected between and fluidly connected to the at least one heat exchanger units 500 and the at least one gas separator unit 600.

[000222] As shown in FIG. 1A, according to various embodiments, the system 100 may include at least one product separation and purification unit 700. According to various

embodiments, the at least one product separation and purification unit 700 may be positioned downstream of the at least one gas separator unit 600. According to various embodiments, the at least one product separation and purification unit 700 may be connected or fluidly connected to the at least one gas separator unit 600. According to various
 5 embodiments, the at least one product separation and purification unit 700 may separate and purify the pyrolysis gas product into one or more (e.g. to achieve a desired) hydrocarbon products or the final products 701, including, but not limited to hydrocarbon having carbon atoms in the range of C₂ to C₃₄, such as hydrocarbon that is suitable for petrochemical process or fuel (e.g. Naphtha, Diesel, or other hydrocarbons etc.). According to various
 10 embodiments, the pyrolysis gas product from the at least one gas separator unit 600 may be received in or may enter the at least one product separation and purification unit 700 for separation and purification.

[000223] According to various embodiments, there is provided a method of converting waste plastic materials to useful products. The method may include any one or more of the
 15 steps described herein as well as any corresponding features described herein.

[000224] According to various embodiments, the method may include introducing the waste plastic materials to the system 100.

[000225] According to various embodiments, the method may include compressing the waste plastic materials to form the compressed waste plastic feed, for example, via the waste
 20 materials compression unit 200. According to various embodiments, the method may include compressing the waste plastic materials via the waste materials compression unit 200 by a compression ratio in a range of substantially 2.0 to 5.0. According to various embodiments, compressing the waste plastic materials via the waste materials compression unit 200 may remove air such that the compressed waste plastic feed output from the waste
 25 materials compression unit 200 may have air (e.g. oxygen) content within a range of substantially 2%wt to 16%wt, preferably 5%wt to 10%wt. According to various embodiments, compressing the waste plastic materials via the waste materials compression unit 200 may remove moisture such that the compressed waste plastic feed output from the waste materials compression unit 200 may have a moisture content within a range of
 30 substantially 2%wt to 16%wt, preferably 5%wt to 10%wt). According to various embodiments, compressing the waste plastic materials via the waste materials compression unit 200 may be performed at a temperature within a range of substantially 90°C to 140°C, preferably 110°C to 120°C). According to various embodiments, compressing the waste

plastic materials via the waste materials compression unit 200 may be at a pressure in a range of substantially 100 kPa to 190 kPa, preferably 100 kPa to 150 kPa (or 0 barg to 0.9 barg, preferably 0 barg to 0.5 barg, or 1 bar to 1.9 bar, preferably 1 bar to 1.5 bar). According to various embodiments, compressing the waste plastic materials via the waste materials compression unit 200 may be for a duration of time (e.g. a retention time) depending on or based on a flow rate along the waste materials compression unit 200 or a dimension of the waste materials compression unit 200. For example, according to various embodiments, the waste plastic materials may be compressed via the waste materials compression unit 200 for a duration (e.g. a retention time) of substantially 30 seconds to 120 seconds (or 0.5 minutes to 2.0 minutes), preferably 60 seconds to 78 seconds (or 1.0 minutes to 1.3 minutes).

[000226] According to various embodiments, the method may include melting the compressed waste plastic feed, for example, via the melting stage 310, by heating the compressed waste plastic feed at a temperature equal to or higher than a melting point of the compressed waste plastic feed to form the melted mixture. According to various embodiments, the temperature may be within a range of substantially 110°C to 160°C, preferably 120°C to 140°C. According to various embodiments, melting the compressed waste plastic feed via the melting stage 310 may be for a duration of time (e.g. retention time) depending on or based on a flow rate of the compressed waste plastic feed or melted mixture along the melting stage 310 or a dimension of the melting stage 310 or the reactor having the melting stage 310. For example, according to various embodiments, melting the compressed waste plastic feed via the melting stage 310 may be for a duration (e.g. a retention time) of substantially 18 seconds to 90 seconds (or 0.3 minutes to 1.5 minutes), preferably 48 second to 72 seconds (or 0.8 minutes to 1.2 minutes).

[000227] According to various embodiments, the method may include feeding catalyst at one or more of the different catalyst feeding points (e.g. catalyst feeding ports 32) of the thermal-to-catalytic pyrolysis stage 320 of the system 100 to vary the proportion of the thermal pyrolysis process and the catalytic pyrolysis process in the thermal-to-catalytic pyrolysis stage 320 based on the desired final product 701 to be output from the system 100 or property of the waste plastic materials or feed that is introduced to the system 100.

[000228] According to various embodiments, the thermal pyrolysis process may be conducted at a temperature or temperature range suitable to decompose or break down the waste plastic materials into a size suitable for interacting with the catalyst to transform or change or switch or convert to the catalytic pyrolysis process. According to various

embodiments, the thermal pyrolysis process may be conducted or performed at a temperature or temperature range within a range of substantially 130°C to 370°C, or 150°C to 320°C, or 150°C to 250°C.

5 **[000229]** According to various embodiments, the catalytic pyrolysis process may be conducted or performed at a temperature or temperature range within a range of substantially 250°C to 370°C, preferably 270°C to 320°C.

[000230] According to various embodiments, the method may include heating the pyrolysis solid residue for conversion into the solid product in the termination stage 330. According to various embodiments, the method may include heating the pyrolysis solid residue via the termination stage 330 to a temperature suitable for any one or a combination of (i) breaking any remaining C-H bonds in the pyrolysis solid residue, (ii) removing any hydrogen from the pyrolysis solid residue, and/or (iii) drying the pyrolysis solid residue. According to various embodiments, heating of the pyrolysis solid residue in the termination stage 330 may be conducted or performed at a temperature of at least substantially 350°C.

10 According to various embodiments, the method may include heating the pyrolysis solid residue via the termination stage 330 for a duration of time (e.g. a retention time) depending on or based on a flow rate of the pyrolysis solid residue along the termination stage 330 or an amount of the pyrolysis solid residue or an amount of solid product generated or a dimension of the termination stage 330 or a reactor having the termination stage 330. For example heating the pyrolysis solid residue via the termination stage 330 may be for a duration (e.g. a retention time) of substantially 18 seconds to 210 seconds (or 0.3 minutes to 3.5 minutes), or 42 seconds to 180 seconds (or 0.7 minutes to 3.0 minutes), or 84 seconds to 144 seconds (or 1.4 minutes to 2.4 minutes). According to various embodiments, the method may include heating the pyrolysis solid residue via the termination stage 330 to

20 remove moisture (i.e. from the pyrolysis solid residue) such that the solid product (i.e. produced in the termination stage 330) may have a moisture content within a range of substantially 5%wt to 35%wt, preferably 10%wt to 30%wt) and a solid content within a range of substantially 60%wt to 95%wt, preferably 70%wt to 90%wt).

[000231] According to various embodiments, the melting of compressed waste plastic feed, the thermal pyrolysis process and/or the catalytic pyrolysis process, and the heating of the pyrolysis solid residue in the termination stage 330 may be performed at the same pressure. According to various embodiments, the pressure may be within a range of

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substantially 120 kPa to 180 kPa, preferably 140 kPa to 160 kPa (0.2 barg to 0.8 barg, preferably 0.4 barg to 0.6 barg, or 1.2 bar to 1.8 bar, preferably 1.4 bar to 1.6 bar).

[000232] According to various embodiments, the method may include removing the solid product from the termination stage 330.

5 **[000233]** According to various embodiments, removing the solid product from the termination stage 330 may include waiting and/or allowing the solid product to build up in the termination stage 330 in a manner such that the built-up (or remaining) solid product in the termination stage 330 may block the pyrolysis solid outlet 332 of the termination stage 330, without overflowing or escaping unintendedly from the termination stage 330, to
10 prevent a gas leakage from the termination stage 330 through the pyrolysis solid outlet 332.

[000234] According to various embodiments, removing the solid product from the termination stage 330 may include removing the solid product from the termination stage 330 in a continuous manner.

[000235] According to various embodiments, the method may include monitoring a
15 property of the final product 701 output from the system 100 (i.e. obtained from the at least one product separation and purification unit 700) to determine whether an adjustment of the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage 320 is required for generating the desired final product 701 to be output from the system 100. For example, according to various embodiments, the
20 final products 701 in the form of the one or more hydrocarbon products obtained from the at least one product separation and purification unit 700 may be an initial sample or initial iteration of the final product 701 initially output from the system 100. The property monitored may be or may include specific gravity of these final product 701 initially output from the system 100 and/or any other suitable property or properties. According to various
25 embodiments, based on the monitored or determined property or properties (e.g. specific gravity) of these final product 701 initially output from the system 100, it may be determined whether to add catalyst in the at least one intermediate variable zones 322 and/or in the final catalytic pyrolysis zone 324 in order to achieve the desired final product 701. Accordingly, determining an adjustment of the proportion of the thermal pyrolysis process and the
30 catalytic pyrolysis process required may be based on an iterative process until the desired final product 701 is achieved.

[000236] For example, upon start-up of the system 100 or at the start of the method, catalyst may be fed to one of the catalyst feeding points (“initial catalyst feeding point”) of

the system 100. According to various embodiments, the initial catalyst feeding point may be an arbitrarily selection, such as the feeding port 32b of the final catalytic pyrolysis zone 324. Then, the property or properties of the final product 701 initially output from the system 100, which may be an initial sample or initial iteration of the final product 701, may be monitored to determine whether the final product 701 initially output from the system 100 has the same property or properties (e.g. specific gravity etc.) as the desire final product 701. If not, then the point(s) at which the catalyst is fed into the system 100 may be adjusted in a manner to vary the final product 701 correspondingly output from the system 100. The point(s) at which the catalyst is fed may be adjusted until the final product 701 correspondingly output from the system 100 matches the desired final product 701. If a longer catalytic cracking time for the waste plastic materials is required in order to produce the desired final product 701, the catalyst may be added earlier into the system 100 (e.g. at a catalyst feeding point nearer to the melting stage 310). According to various embodiments, the adjusted point(s) at which the catalyst is fed into the system 100 may include or may differ from the initial catalyst feeding point.

[000237] According to various embodiments, the adjustment of the proportion of the thermal pyrolysis process and the catalytic pyrolysis process may include an adjustment of a retention time of the thermal pyrolysis process and/or a retention time of the catalytic pyrolysis process.

[000238] According to various embodiments, determining the proportion or an adjustment of the proportion of the thermal pyrolysis process and the catalytic pyrolysis process required may be based on a composition of the waste plastic materials and/or a type of catalyst to be used.

[000239] According to various embodiments, the method may include withdrawing the pyrolysis gas product from the continuous thermal treatment arrangement 300. In particular, according to various embodiments, the method may include withdrawing the pyrolysis gas product from the thermal-to-catalytic pyrolysis stage 320 and/or the termination stage 330 of the continuous thermal treatment arrangement 300 of the system 100.

[000240] According to various embodiments, the method may include condensing (e.g. some) long chain carbon compounds from the pyrolysis gas product by the at least one heat exchanger units 500. According to various embodiments, condensing long chain carbon compounds in the pyrolysis gas product by the at least one heat exchanger units 500 may be performed after the withdrawing of the pyrolysis gas product from the thermal-to-catalytic

pyrolysis stage 320. According to various embodiments, the method may include returning or recycling the condensed long chain carbon compounds into the thermal-to-catalytic pyrolysis stage 320. For example, the condensed long chain carbons may be directed or flow back into the thermal-to-catalytic pyrolysis stage 320, for example, via gravity as recycled wax.

[000241] According to various embodiments, the method may include removing particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product, for example, by the at least one gas separator unit 600. According to various embodiments, removing the particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product by the at least one gas separator unit 600 may be performed on the pyrolysis gas product after passing through the at least one heat exchanger units 500. According to various embodiments, the method may include returning or recycling the particulate and/or the heavy hydrocarbon removed by the at least one gas separator unit 600 to the thermal-to-catalytic pyrolysis stage 320. For example, the removed particulate and/or the heavy hydrocarbon may be directed or re-entered into the thermal-to-catalytic pyrolysis stage 320 after the pyrolysis gas product has been processed by the at least one gas separator unit 600. According to various embodiments, the method may include processing (e.g. melting and/or undergoing a pyrolysis process and/or heating) the particulate and/or the heavy hydrocarbon that are returned to the thermal-to-catalytic pyrolysis stage 320.

[000242] According to various embodiments, before entering the at least one gas separator unit 600, the pyrolysis gas product may enter or pass through or be processed by other equipment, such as distillation column(s) interconnected between and fluidly connected to the at least one heat exchanger units 500 and the at least one gas separator unit 600.

[000243] According to various embodiments, the method may include separating and purifying the pyrolysis gas product from the at least one gas separator unit 600 into the one or more hydrocarbon products or the final product 701, e.g. hydrocarbon having carbon atoms in the range of C2 to C34, such as hydrocarbon that is suitable for petrochemical process or fuel, e.g. Naphtha, Diesel, or other hydrocarbons etc. Accordingly, after the pyrolysis gas product has been processed by the at least one gas separator unit 600, the processed pyrolysis gas product may be directed to the at least one product separation and purification unit 700 for separation and purification of the pyrolysis gas product into the one or more final products 701 (e.g. hydrocarbon having carbon atoms in the range of C2 to C34,

such as hydrocarbon that is suitable for petrochemical process or fuel, e.g. Naphtha, Diesel, or other hydrocarbons etc.).

[000244] Some operating examples of the system and method according to various embodiments will be described below by way of reference to Examples (A) and (B).

- 5 **[000245]** The examples (i.e. Examples (A) and (B)) described in the following may run or be operated in a pilot system (or trial system or experimental system) built according to the system 100 of the various embodiments, whereby the melting stage, the thermal-to-catalytic pyrolysis stage and the termination stage of the pilot system may be conducted in a multi-zone reactor. According to various embodiments, the total length of the reactor may
- 10 be 16 m, whereby a length from a first end of the reactor (e.g. at the melting stage) to a first catalyst feeding port (e.g. nearest to the melting stage) may be 3 m, a length from the first end of the reactor to a second catalyst feeding port may be 6 m, and a length from the first end of the reactor to a third catalyst feeding port may be 9 m.

[000246] Example (A):

- 15 **[000247]** The feed used in the pilot system may include a mixed waste plastic including 50%wt of 'PVC 7%, PE 55%, PP 31%, PS 4%, and others 3%', 20 to 30%wt of moisture, and 20 to 30%wt of sand and stone. The feed may be compressed in a compression stage (e.g. waste materials compression unit) at a temperature of around 115°C. The compressed feed may be introduced to the reactor at the first end of the reactor where the melting stage
- 20 is conducted, at a temperature of around 130°C to form a melted mixture. Then, the melted mixture may be transferred to the thermal-to-catalytic pyrolysis stage where thermal pyrolysis is first conducted, at a temperature of around 270°C, before the catalyst is added via the second catalyst feeding port (i.e. 6m from the first end of the reactor). After the catalyst is added, the thermal pyrolysis process may be transformed into a catalytic pyrolysis
- 25 process, at a temperature of around 330°C, in the thermal-to-catalytic pyrolysis stage. The pyrolysis gas product produced in the reactor may be drawn from the reactor at the termination stage to enter a double-pipe heat exchanger to condense long chain carbon compounds in the pyrolysis gas product, followed by entering a cyclone separator to remove particulate or heavy hydrocarbon in the pyrolysis gas product. The pyrolysis solid residue
- 30 produced in the reactor may be transferred to the termination stage, which may be operated at 350°C, to break any remaining carbon-hydrogen (C-H) bonds in the pyrolysis solid residue, remove any hydrogen from the pyrolysis solid residue, and/or dry the pyrolysis solid residue to generate (or produce) a solid product. The solid product may be removed

via a solid product compression unit. whereby a rotation speed of the second screw of the solid product compression unit may be around 90% of a rotational speed of the first screw and a rotation speed of the third screw of the solid product compression unit may be around 80% of a rotational speed of the first screw. A Diesel selectivity of the pyrolysis gas product may be 50.10%, and a Naphtha selectivity of the pyrolysis gas product may be 7.40%. The bulk density of the solid product may be 1.91 g/cm³.

[000248] Example (B):

[000249] Example (B) may be operated with the same feed and according to the same conditions as Example (A) except that the catalyst may be added via the first catalyst feeding port (i.e. 3m from the first end of the reactor). A Diesel selectivity of the pyrolysis gas product may be 7.40%, and A Naphtha selectivity of the pyrolysis gas product may be 57.40%. The bulk density of the solid product may be 1.97 g/cm³.

[000250] By comparing Example (A) and Example (B), it may be observed that feeding the catalyst at different catalyst feeding ports may result in different product selectivity. Accordingly, a respective catalyst feeding port may be selected for feeding catalyst into the system based on the required product (i.e. desired final product) or a property or composition of the waste plastic materials or feed that is introduced to the system. Accordingly, various types of waste plastic materials may be converted to useful product by using the system and method according to the various embodiments.

[000251] Various embodiments have provided a system and a method for converting waste plastic materials to useful products. In various embodiments, the system and method may include selectively varying a point along the system where a catalyst is added by way of the at least two catalyst feeding ports provided at different points (i.e. stages) along the system. Accordingly, the catalyst may be selectively added only at a point of the system where it may optimally perform its function, without wastage of catalyst.

[000252] Further, in various embodiments, the system and the method has provided a versatile and efficient pyrolysis process. In various embodiments, a wide variety of raw material may be used with the system and the method. For example, in various embodiments, contaminated raw material may be used with the system and the method to achieve the desired result. In various embodiments, the system and the method may be easy to control to achieve a desired final product and may be safe to operate.

[000253] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various

changes, modification, variation in form and detail may be made therein without departing from the scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

1. A system for converting waste plastic materials to useful products, the system comprising:
a continuous thermal treatment arrangement having:
 - a melting stage to melt a compressed waste plastic feed generated from the waste plastic materials so as to form a melted mixture,
 - a thermal-to-catalytic pyrolysis stage downstream of the melting stage to subject the melted mixture through a thermal pyrolysis process followed by a catalytic pyrolysis process for producing a pyrolysis gas product and a pyrolysis solid residue, wherein the thermal-to-catalytic pyrolysis stage comprises at least two catalyst feeding points distributed along the thermal-to-catalytic pyrolysis stage, wherein the thermal-to-catalytic pyrolysis stage is operable to selectively feed a catalyst via any one or more of the at least two catalyst feeding points for transforming the thermal pyrolysis process to the catalytic pyrolysis process at different points along the thermal-to-catalytic pyrolysis stage in a manner so as to vary a proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage, and
 - a termination stage downstream of the thermal-to-catalytic pyrolysis stage to heat the pyrolysis solid residue for conversion into a solid product.
2. The system of claim 1, further comprising:
a waste materials compression unit upstream of the continuous thermal treatment arrangement, the waste materials compression unit operable to compress the waste plastic materials to remove air and moisture so as to generate the compressed waste plastic feed for feeding into the continuous thermal treatment arrangement
3. The system of claim 1 or 2, wherein the thermal-to-catalytic pyrolysis stage comprises
an initial thermal pyrolysis zone to heat the melted mixture received from the melting stage at or above a thermal decomposition temperature of the melted mixture,

one or more intermediate variable zones, each intermediate variable zone having a catalyst feeding port at a start of the intermediate variable zone, the catalyst feeding port serving as one of the at least two catalyst feeding points along the thermal-to-catalytic pyrolysis stage, and

a final catalytic pyrolysis zone having a catalyst feeding port at a start of the final catalytic pyrolysis zone serving as a final catalyst feeding point of the at least two catalyst feeding points along the thermal-to-catalytic pyrolysis stage for receiving the catalyst,

wherein the catalyst is fed through the catalyst feeding port of the one or more intermediate variable zones or the catalyst feeding port of the final catalytic pyrolysis zone for transforming the thermal pyrolysis process to the catalytic pyrolysis process at the different points along the thermal-to-catalytic pyrolysis stage.

4. The system of claim 3, wherein the continuous thermal treatment arrangement comprises at least one pyrolysis gas outlet to release the pyrolysis gas product , wherein the at least one pyrolysis gas outlet is at the final catalytic pyrolysis zone of the thermal-to-catalytic pyrolysis stage or at the termination stage or both, wherein the at least one pyrolysis gas outlet comprises a vacuum pump.
5. The system of claim 4, further comprising at least one heat exchanger unit connected to the at least one pyrolysis gas outlet to condense long chain carbon compounds in the pyrolysis gas product,
6. The system of claim 5, further comprising at least one gas separator unit downstream of the at least one heat exchanger unit to remove residue particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product.
7. The system of any one of claims 1 to 6, wherein the termination stage comprises at least one solid product outlet for discharging the solid product.

8. The system of any one of claims 1 to 7, wherein the continuous thermal treatment arrangement comprises a reactor comprising any one or a combination of the melting stage, the thermal-to-catalytic pyrolysis stage, or the termination stage.
9. The system of claim 8, wherein the reactor is inclined in a rise per run ratio of 1:250-1:20.
10. The system of any one of claims 2 to 9 in combination with claim 2, wherein the waste materials compression unit comprises at least two rotatable screws arranged in series from an entrance of the waste materials compression unit to an exit of the waste materials compression unit, wherein a direction of solid transfer is from the entrance of the waste materials compression unit to the exit of the waste materials compression unit.
11. The system of claim 10, wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the waste materials compression unit decreases sequentially one after another from the entrance of the waste materials compression unit to the exit of the waste materials compression unit to compress the waste plastic materials into the compressed waste plastic feed.
12. The system of any one of claims 1 to 11 further comprising at least one solid product compression unit to compress the solid product discharge from the termination stage of the continuous thermal treatment arrangement, wherein the solid product compression unit is downstream of the termination stage of the continuous thermal treatment arrangement.
13. The system of claim 12, wherein the solid product compression unit comprises at least two rotatable screws arranged in series from an entrance of the solid product compression unit to an exit of the solid product compression unit, wherein a direction of solid transfer is from the entrance of the solid product compression unit to the exit of the solid product compression unit.

14. The system of claim 13, wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit to compress the solid product.
15. The system of claim 13 or 14, wherein a rotational speed of each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit.
16. The system of any one of claims 13 to 15, wherein the solid product compression unit further comprises at least three rotatable screw .
17. A method of converting waste plastic materials to useful products, the method comprising;
 - introducing a compressed waste plastic feed generated from the waste plastic materials to a melting stage of a continuous thermal treatment arrangement of a system for converting waste plastic materials to useful products, wherein the melting stage melts the compressed waste plastic feed to form a melted mixture;
 - selectively feeding a catalyst via any one or more of at least two catalyst feeding points of a thermal-to-catalytic pyrolysis stage of the continuous thermal treatment arrangement of the system to vary a proportion of a thermal pyrolysis process and a catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage, wherein the thermal-to-catalytic pyrolysis stage is downstream of the melting stage and subjects the melted mixture through the thermal pyrolysis process followed by the catalytic pyrolysis process for producing a pyrolysis gas product and a pyrolysis solid residue; and
 - removing a solid product from a termination stage of the continuous thermal treatment arrangement of the system, wherein the termination stage is downstream of the thermal-to-catalytic pyrolysis stage and heats the pyrolysis solid residue for conversion into the solid product.

18. The method of claim 17 further comprising
monitoring at least one property of a final product output from the system to determine whether an adjustment of the proportion of the thermal pyrolysis process and the catalytic pyrolysis process within the thermal-to-catalytic pyrolysis stage is required for generating the desired final product to be output from the system, and
selectively feeding the catalyst via any one or more of the at least two catalyst feeding points based on the proportion of the thermal pyrolysis process and the catalytic pyrolysis process determined to be required.
19. The method of claim 17 or 18 further comprising withdrawing the pyrolysis gas product from the continuous thermal treatment arrangement via at least one pyrolysis gas outlet of the continuous thermal treatment arrangement.
20. The method of claim 19, further comprising
condensing long chain carbon compounds from the pyrolysis gas product by at least one heat exchanger unit connected to the at least one pyrolysis gas outlet, and
returning the long chain carbon compounds into the thermal-to-catalytic pyrolysis stage.
21. The method of claim 20, further comprising
removing residue particulate or heavy hydrocarbon or a combination thereof from the pyrolysis gas product by at least one gas separator unit downstream of the at least one heat exchanger unit, and
returning the residue particulate or the heavy hydrocarbon or the combination thereof to the thermal-to-catalytic pyrolysis stage.
22. The method of any one of claims 17 to 21, further comprising compressing the waste plastic materials via a waste materials compression unit, wherein the waste materials compression unit is upstream of the continuous thermal treatment arrangement of the system for converting waste plastic materials to useful products.
23. The method of any one of claims 17 to 22, further comprising

removing the solid product from a termination stage of the continuous thermal treatment arrangement of the system via a solid product compression unit, wherein the solid product compression unit comprises at least two rotatable screws arranged in series from an entrance of the solid product compression unit to an exit of the solid product compression unit, wherein a direction of solid transfer is from the entrance of the solid product compression unit to the exit of the solid product compression unit.

24. The method of claim 23, wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit to compress the solid product.
25. The method of claim 23, wherein a rotational speed of each of the at least two rotatable screws of the solid product compression unit decreases sequentially one after another from the entrance of the solid product compression unit to the exit of the solid product compression unit.
26. A solid compression unit comprising at least two rotatable screws arranged in series from an entrance of the solid compression unit to an exit of the solid compression unit, wherein the at least two rotatable screws are cooperatively operable to compress solid materials as the at least two rotatable screws move the solid materials from the entrance of the solid compression unit to the exit of the solid compression unit.
27. The solid compression unit of claim 26, wherein a volumetric rate of flow generated by each of the at least two rotatable screws of the solid compression unit decreases sequentially one after another from the entrance of the solid compression unit to the exit of the solid compression unit so as to be cooperatively operated to compress the solid materials as the solid materials is being moved from the entrance of the solid compression unit to the exit of the solid compression unit.
28. The solid compression unit of claim 26 or 27, wherein a rotational speed of each of the at least two rotatable screws of the solid compression unit decreases sequentially

one after another from the entrance of the solid compression unit to the exit of the solid compression unit.

29. The solid compression unit of claim 26 or 27, wherein a diameter of a screw shaft of each of the at least two rotatable screws of the solid compression unit increases sequentially one after another from the entrance of the solid compression unit to the exit of the solid compression unit.
30. The solid compression unit of claim 26 or 27, wherein a pitch range of each of the at least two rotatable screws of the solid compression unit decreases sequentially, one rotatable screw after another rotatable screw, from the entrance of the solid compression unit to the exit of the solid compression unit
31. The solid compression unit of any one of claims 26 to 30, further comprising at least three rotatable screws.
32. The solid compression unit of any one of claims 26 to 31, further comprising a cooling jacket surrounding at least one rotatable screw.