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(54) **MEASURING APPARATUS OF BULK VISCOSITY OF MOLDING MATERIAL**

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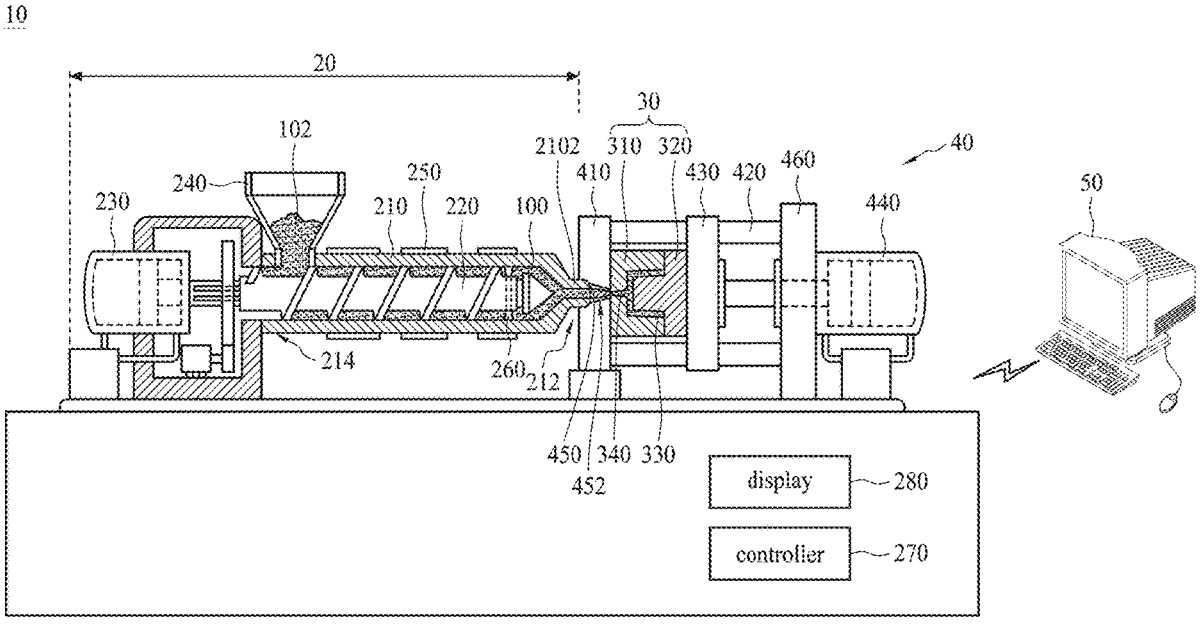
(57) **ABSTRACT**

A measuring apparatus of bulk viscosity includes a temperature-controlling cylinder having a test chamber for holding a molding material and at least one piston configured to seal an opening of the temperature-controlling cylinder. The temperature-controlling cylinder and the at least one piston are configured for measuring pressures, specific volumes and temperatures (PVT) of the molding material by applying a plurality of cooling rates to the molding material inside the testing chamber under an isobaric environment, or applying a plurality of mechanical pressures to the molding material inside the testing chamber under an isothermal environment. The measuring apparatus further includes a process module configured for deriving a plurality of parameters in relation to the pressures, specific volumes and temperatures (PVT) of the molding material based on the measurement; deriving an equilibrium pressure based on the plurality of parameters obtained from a first slowest cooling rate among the plurality of cooling rates.



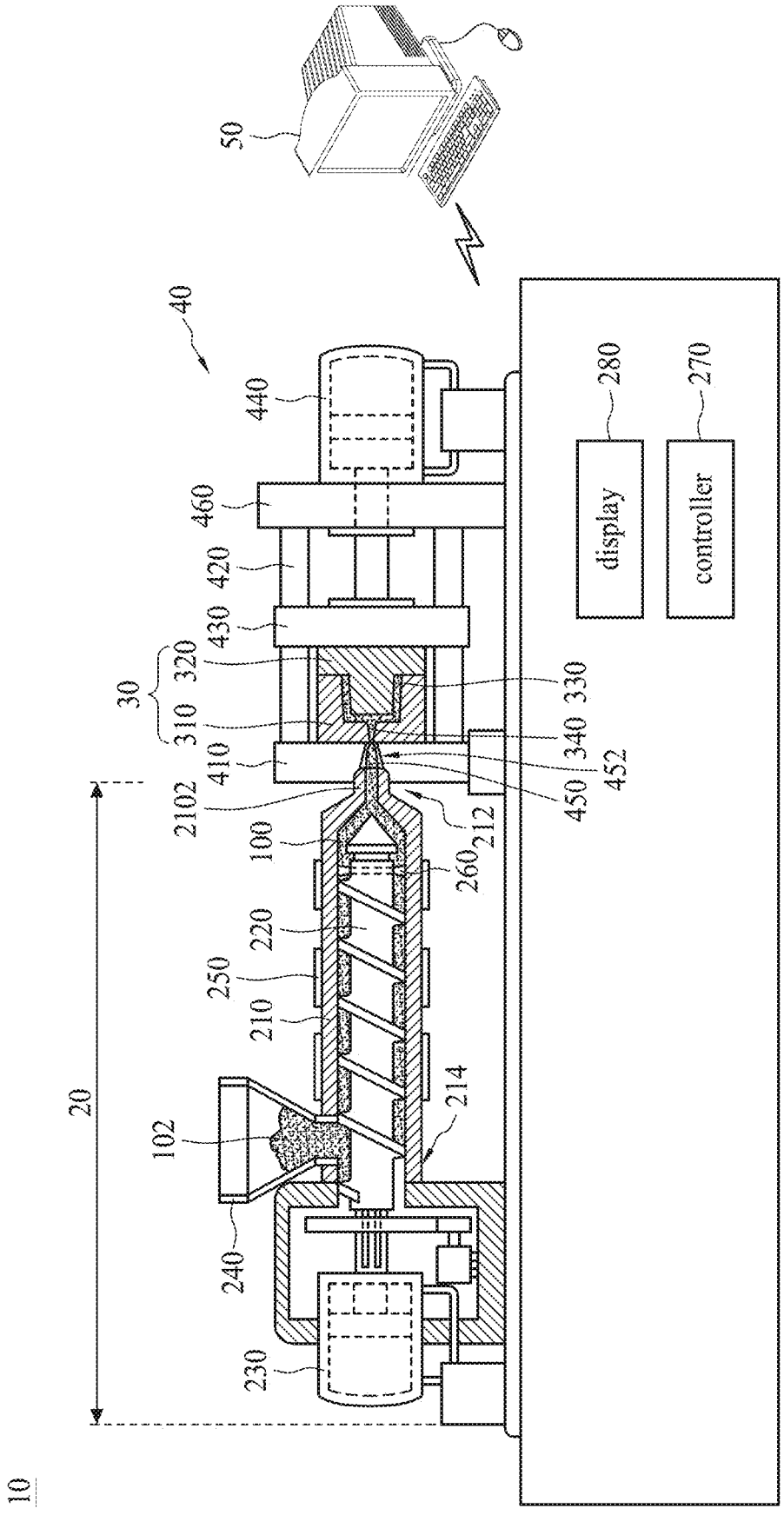

50
40
440
460
420
430
320
310
30
330
340
452
450
410
2102
212
100
260
220
250
210
214
102
240
230
20
10
280
display
270
controller

FIG. 1

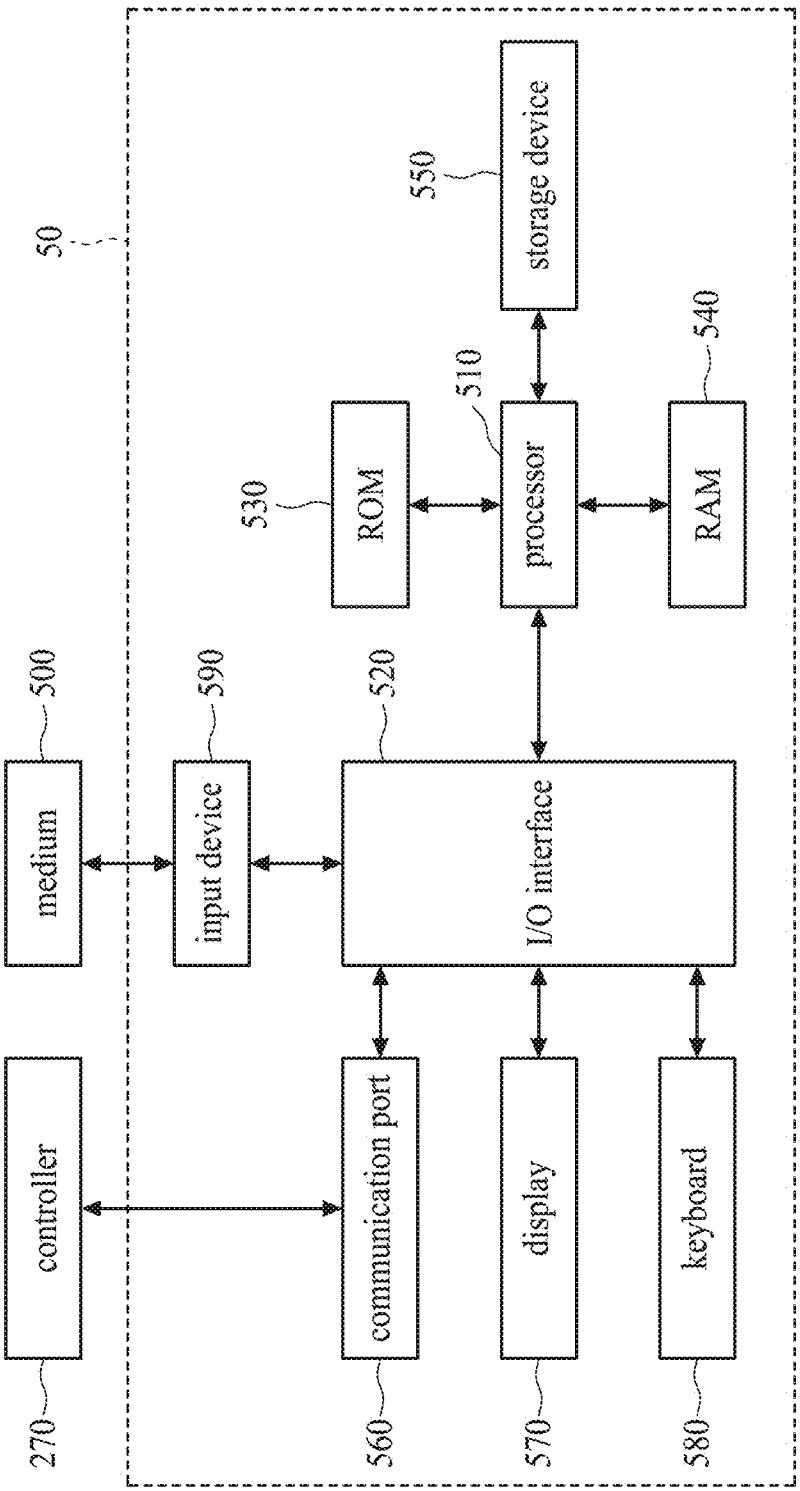

50
storage device
550
540
510
530
ROM
processor
RAM
500
590
520
medium
input device
I/O interface
controller
communication port
display
keyboard
270
560
570
580

FIG. 2

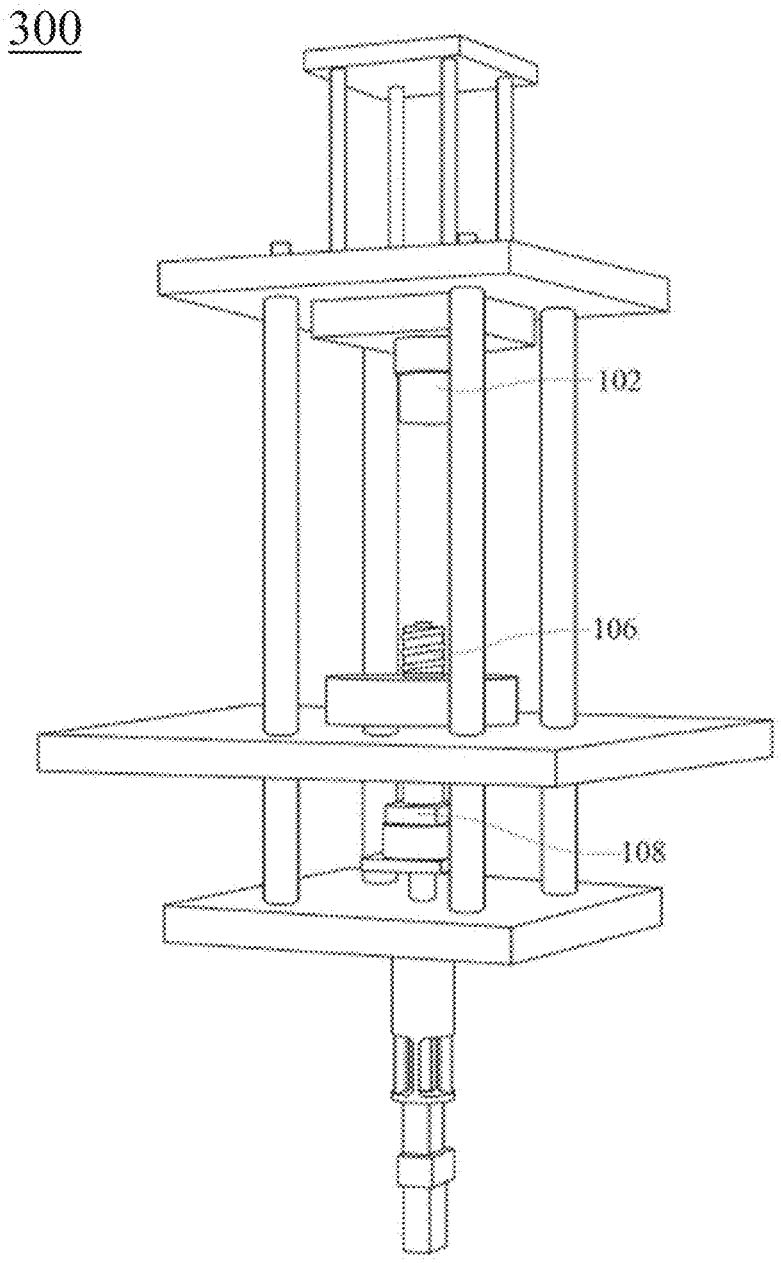


FIG. 3

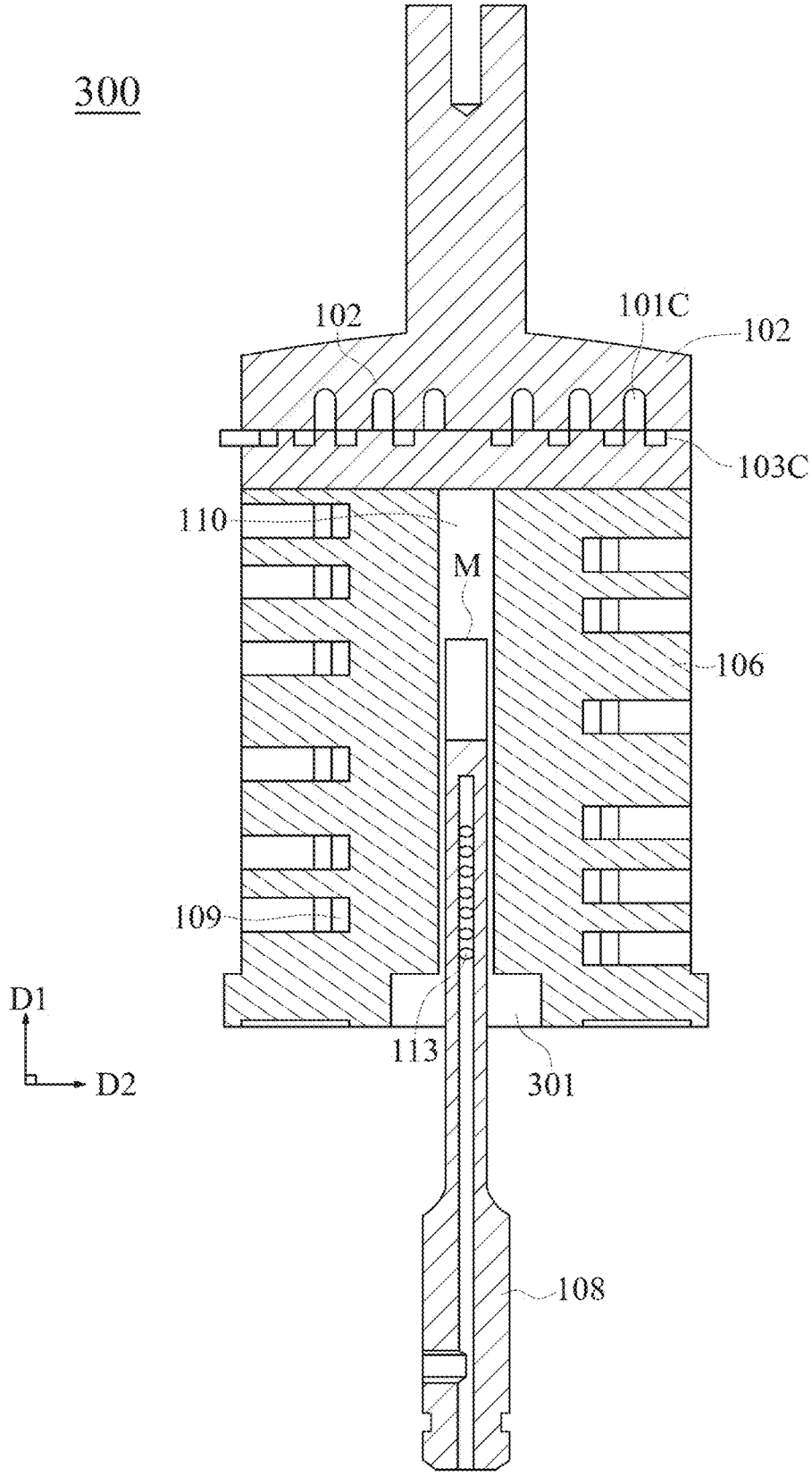


FIG. 4

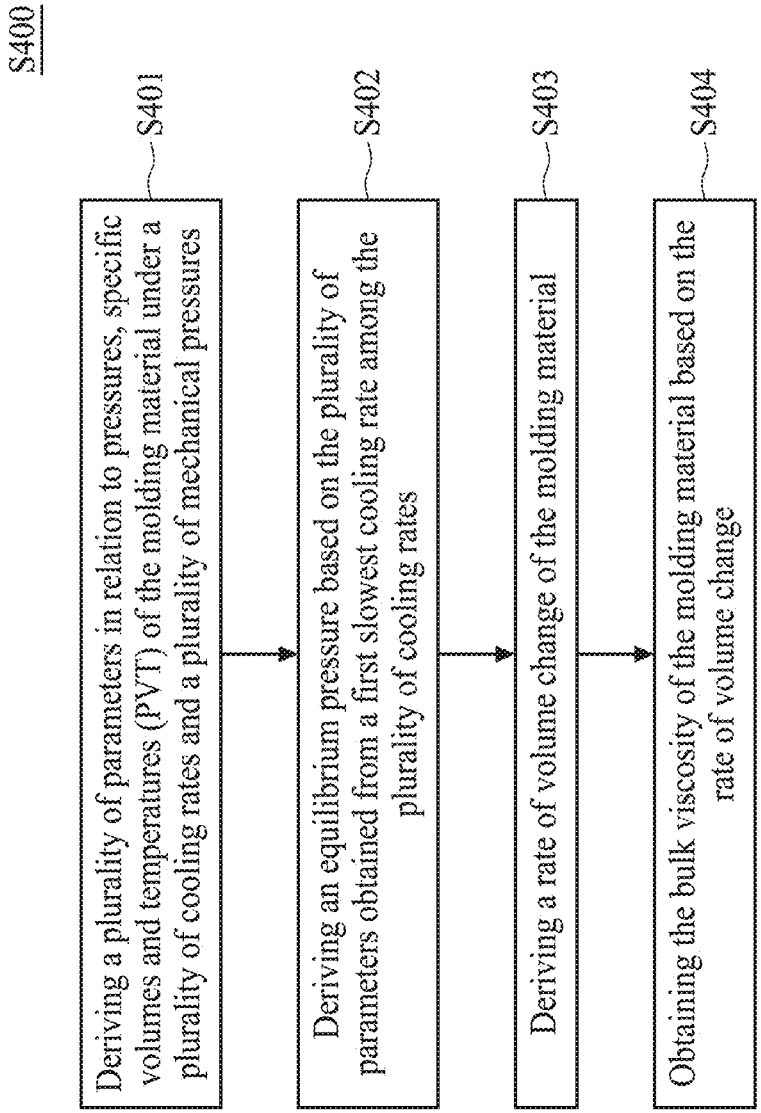

S400
S401
Deriving a plurality of parameters in relation to pressures, specific volumes and temperatures (PVT) of the molding material under a plurality of cooling rates and a plurality of mechanical pressures
S402
Deriving an equilibrium pressure based on the plurality of parameters obtained from a first slowest cooling rate among the plurality of cooling rates
S403
Deriving a rate of volume change of the molding material
S404
Obtaining the bulk viscosity of the molding material based on the rate of volume change

FIG. 5

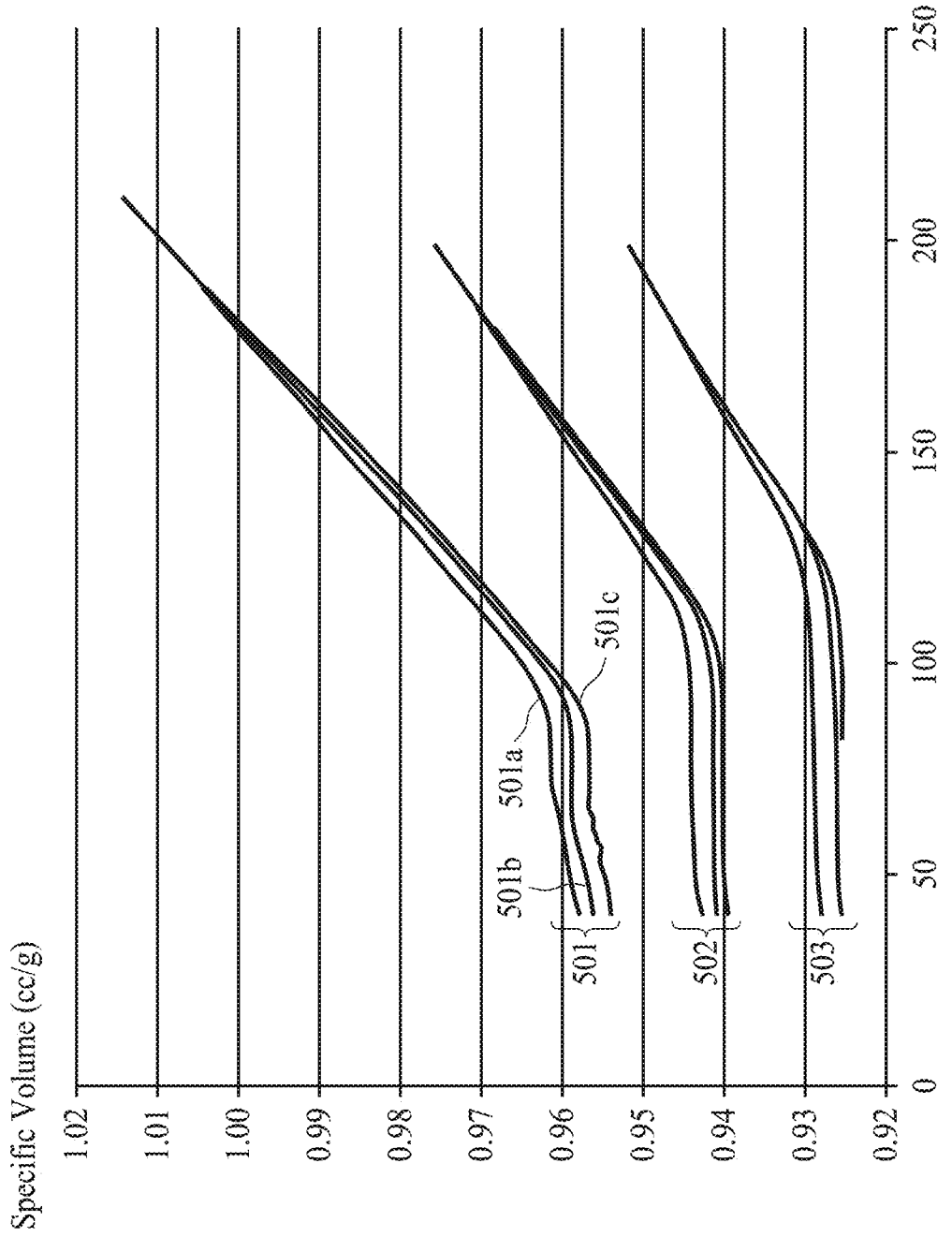

Specific Volume (cc/g)
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0
50
100
150
200
250
Temperature (°C)
501
501a
501b
501c
502
503

FIG. 6

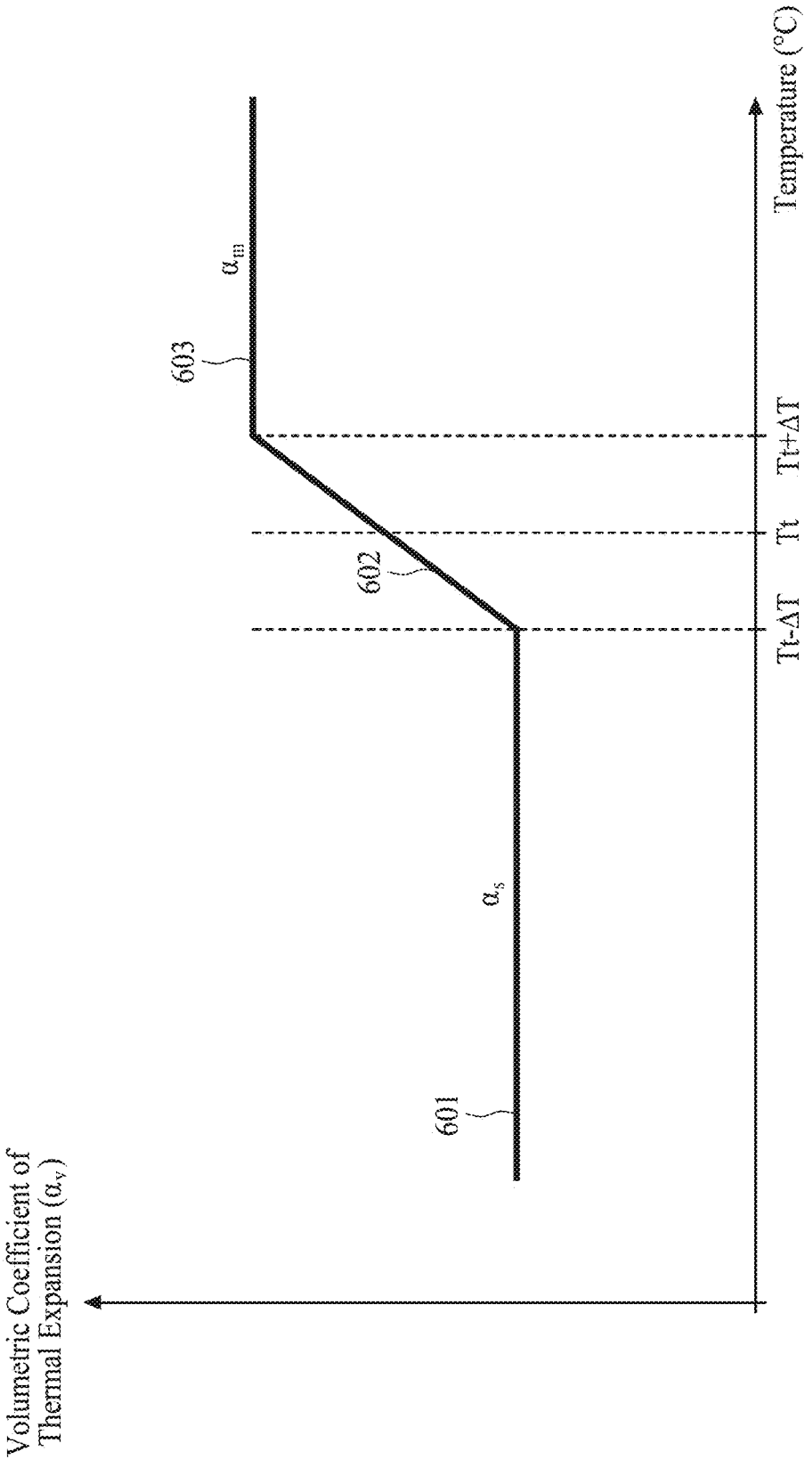

Volumetric Coefficient of Thermal Expansion (α_v)
Temperature (°C)
α_m
α_s
601
602
603
Tt-ΔT
Tt
Tt+ΔT

FIG. 7

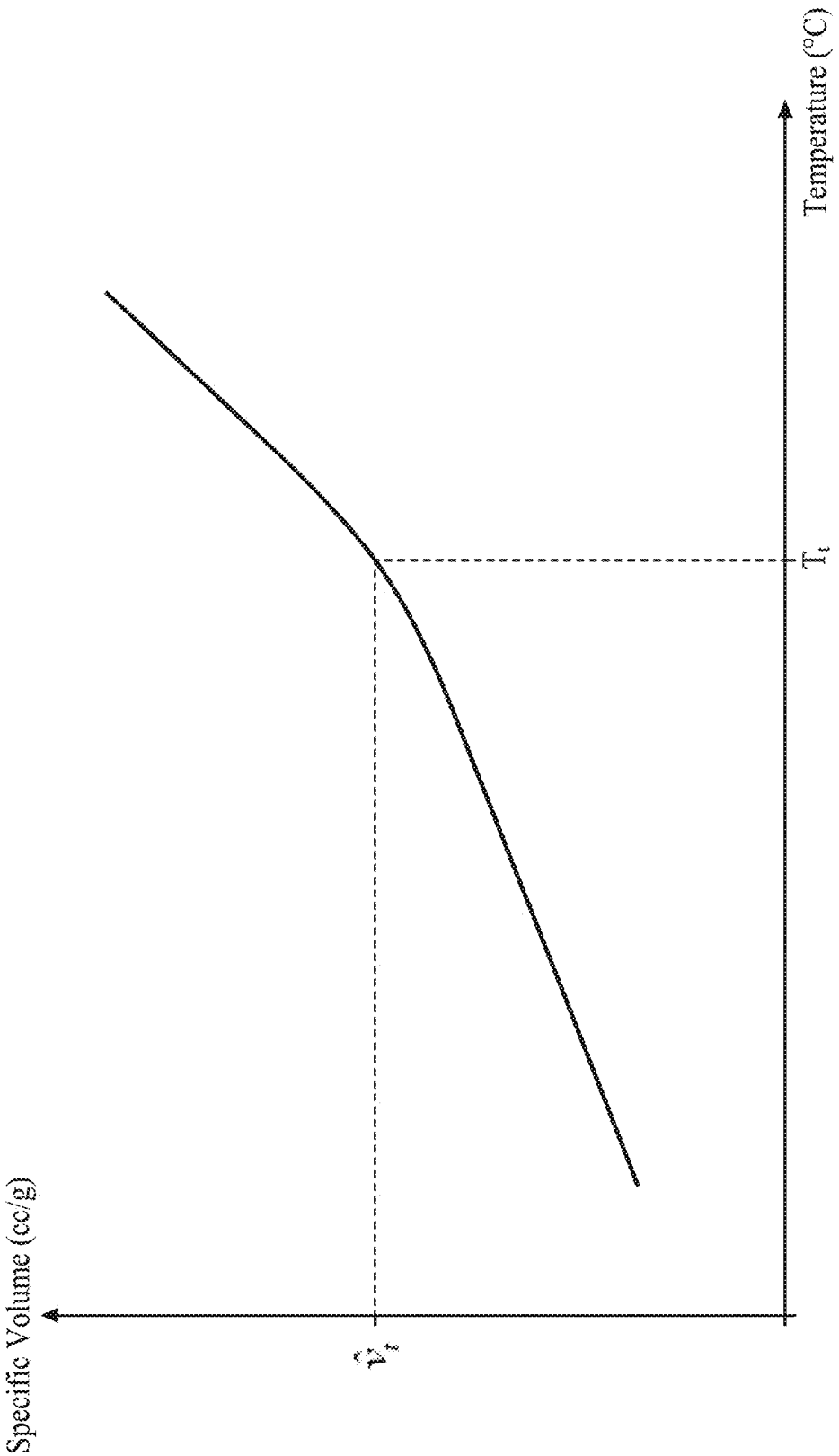


FIG. 8

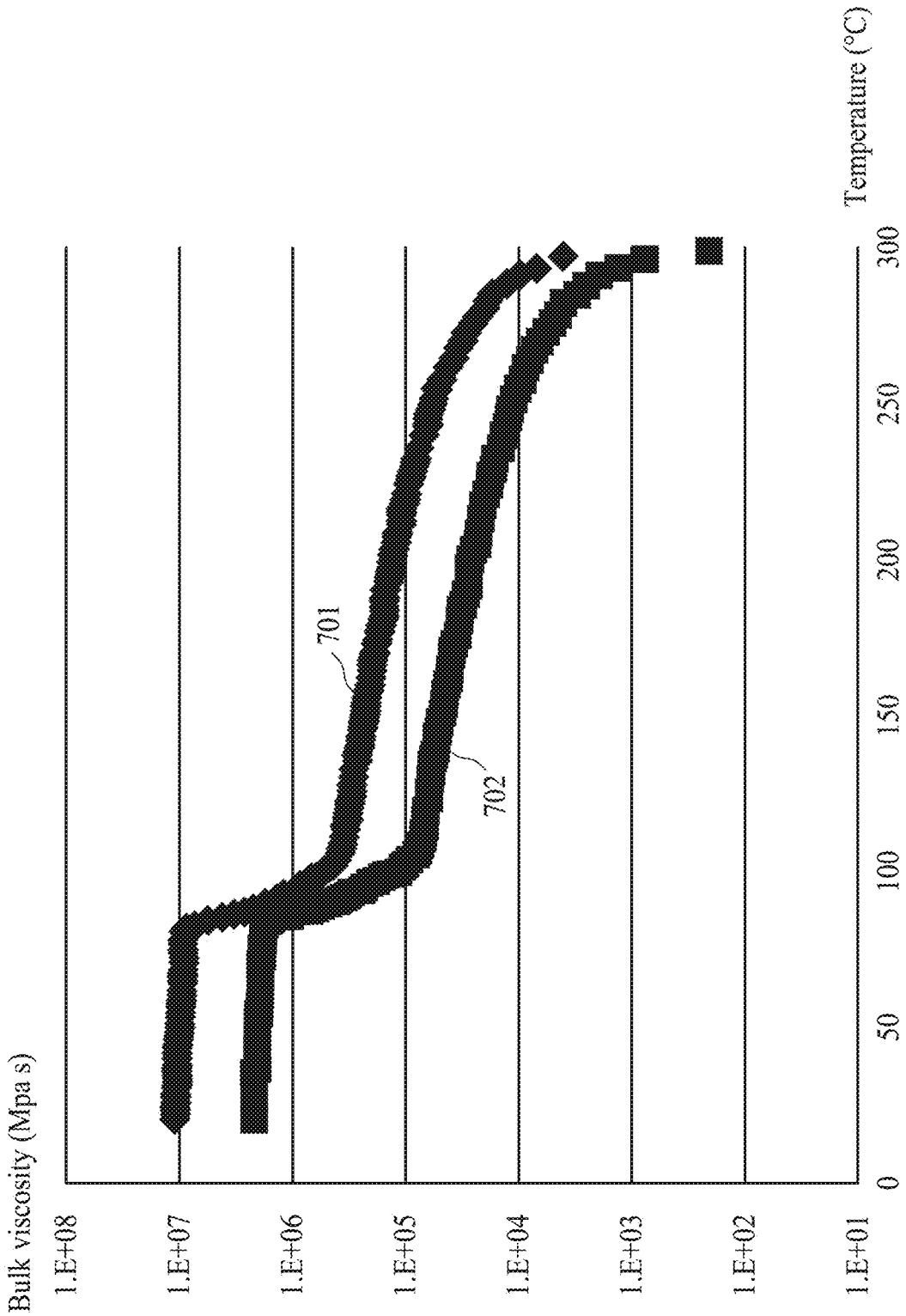

Bulk viscosity (Mpa s)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
0
50
100
150
200
250
300
Temperature (°C)
701
702

FIG. 9

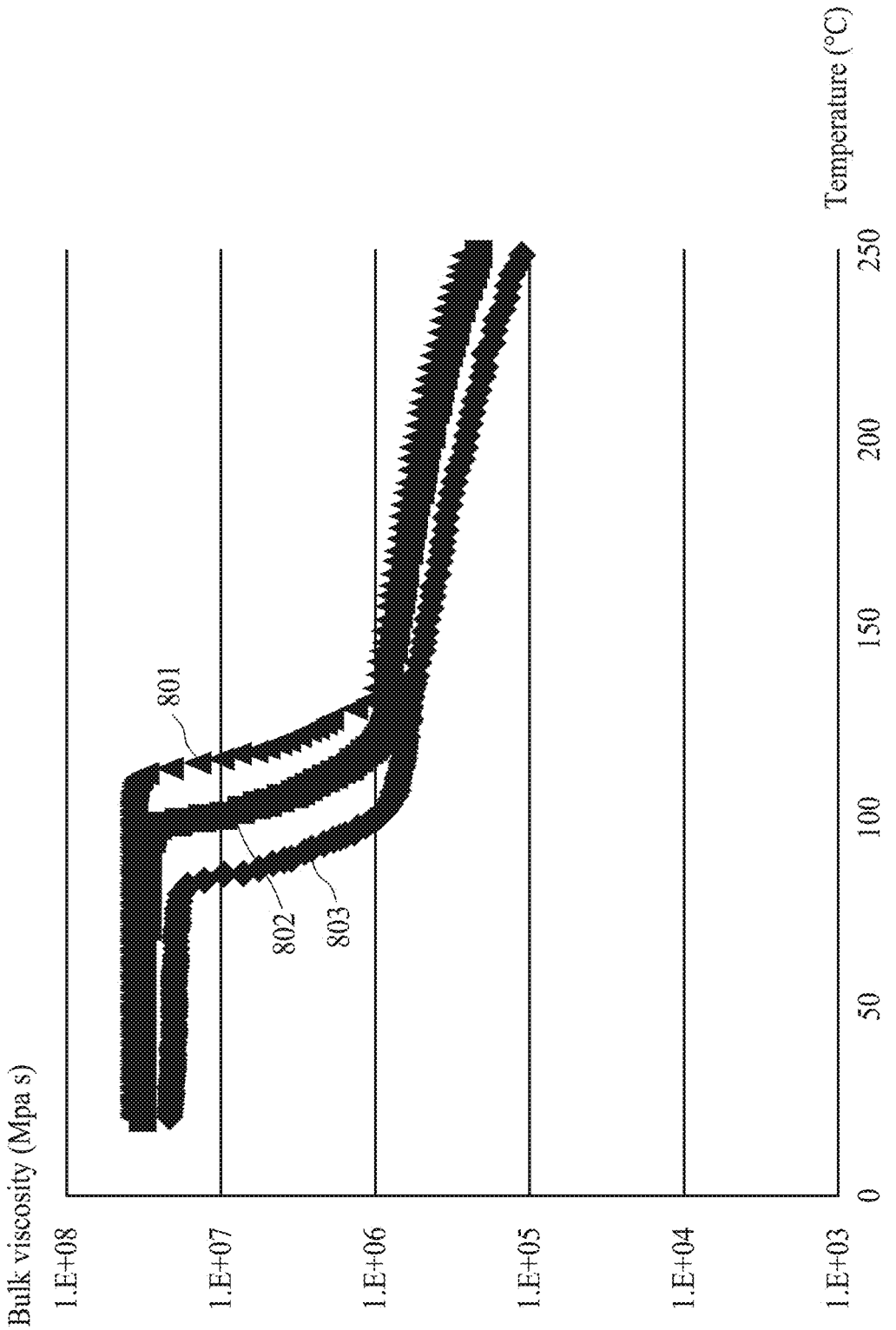

Bulk viscosity (Mpa s)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
0
50
100
150
200
250
Temperature (°C)
801
802
803

FIG. 10

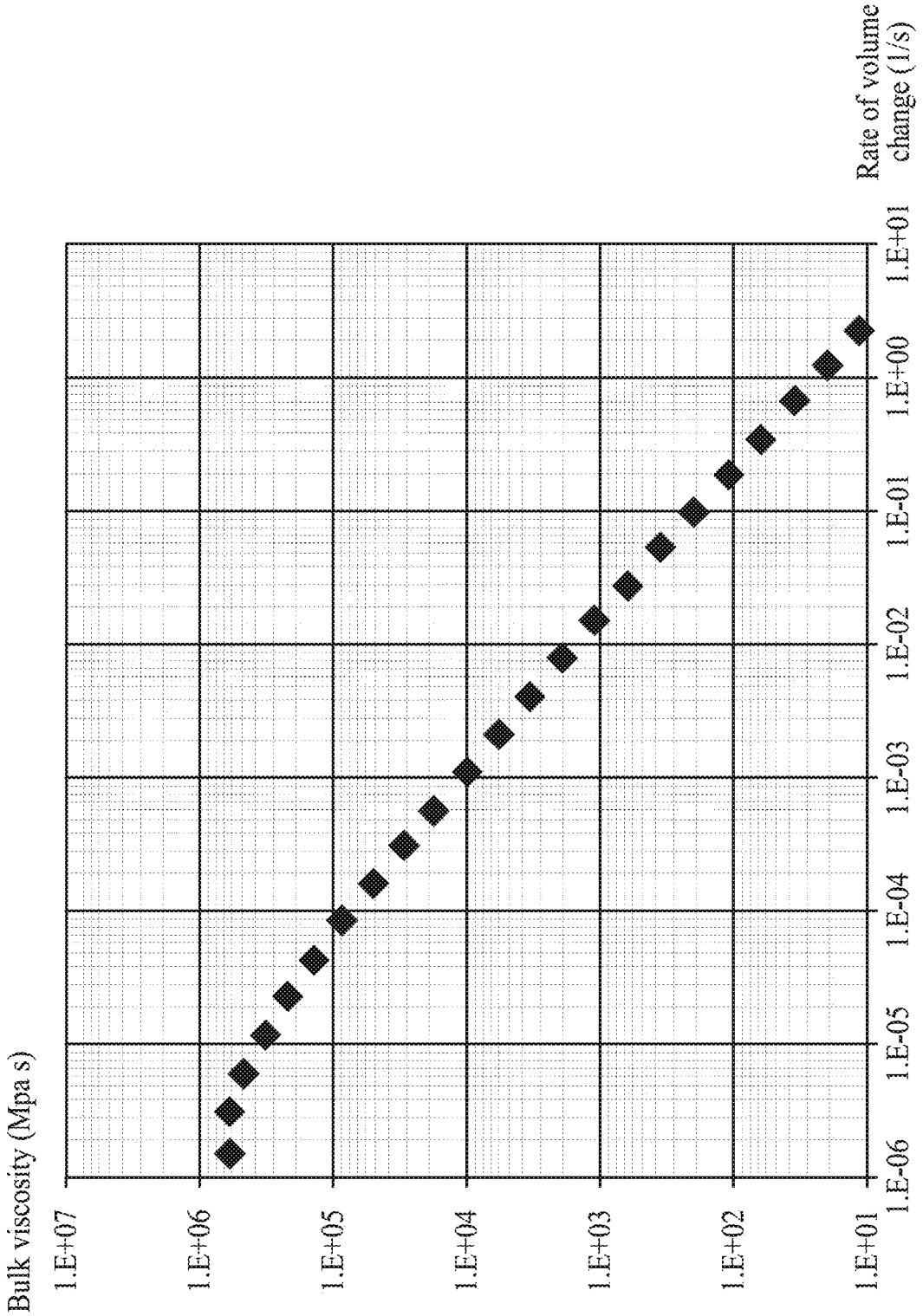

Bulk viscosity (Mpa s)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
Rate of volume change (1/s)

FIG. 11

MEASURING APPARATUS OF BULK VISCOSITY OF MOLDING MATERIAL

PRIORITY CLAIM AND CROSS-REFERENCE

[0001] This application is a continuation of application Ser. No. 17/020,101, filed Sep. 14, 2020, which claims the benefit of prior-filed provisional application with application No. 62/960,201, filed Jan. 13, 2020, and the benefit of prior-filed provisional application with application No. 62/960,206, filed Jan. 13, 2020. These disclosures are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to a measuring apparatus of a bulk viscosity of molding material, and more particularly, to a measuring apparatus of the bulk viscosity of molding material under different cooling rates and different mechanical pressures.

DISCUSSION OF THE BACKGROUND

[0003] Injection molding is a technology commonly used for high-volume manufacturing of parts made of synthetic resin, most commonly made of thermoplastic polymers. During a repetitive injection molding process, a plastic resin, most often in the form of small beads or pellets, is introduced to an injection molding machine that melts the resin beads under heat, pressure, and shear. The resulting molten resin is forcefully injected into a mold cavity having a particular cavity shape. The injected plastic is held under pressure in the mold cavity, cooled, and then removed as a solidified part having a shape that essentially duplicates the cavity shape of the mold.

[0004] A typical injection molding process comprises four basic operations: (1) heating the plastic in the injection molding machine to allow it to flow under pressure; (2) injecting the melted plastic into a mold cavity or cavities defined between two mold halves that have been closed; (3) allowing the plastic to cool and harden in the cavity or cavities while under pressure; and (4) opening the mold halves to cause the part to be ejected from the mold. In the conventional injection molding of synthetic resin by an injection molding machine, the weight of the injected synthetic resin varies with the molten resin pressure, the molten resin specific volume, the molten resin temperature or other molten resin conditions. Therefore, it is difficult to form products of a consistent quality.

[0005] In general, the setting of molding conditions of the injection molding machine requires a large number of trial molding operations and a long setting time because the setting work greatly depends on the know-how and experience of an operator of the injection molding machine, and various physical values affect one another as well.

[0006] Therefore, a virtual molding process, i.e., computer-implemented simulation, using CAE (Computer-Assisted Engineering), is performed for the injection molding, and the molding conditions are then set based on the virtual molding. In virtual molding using CAE, phenomena will occur in a mold cavity within a short period of time. That is, the effects of resin temperature, pressure, shear rate, etc. on molded products can be simulated using CAE. Therefore, if the molding phenomena occurring within a mold cavity can be known accurately, using CAE may enable optimization of molding conditions and a stable molding of non-defective products.

[0007] In plastics manufacturing, the actual flow of polymer melts is transient, non-Newtonian and non-isothermal, with frozen layers building up as the complex mixture flows through the mold cavity. Characteristics of a finished product are determined by many complex factors, such as changes in the direction of flow, inclusion of ribs, and changes in thickness and holes. To control the quality of the products, a deep understanding of complicated flow fields is critical. Nowadays, CAE (computer-aided engineering) software provides realistic simulation and predictive analysis for complex flows of complex fluids.

[0008] The role of bulk viscosity or volume viscosity has been neglected for several decades in the molding flow analysis. This is because the flow of molten plastic in the filling stage is virtually divergence free. Despite the compressional and non-divergence free flow in the packing-holding stage, still the bulk viscosity has been ignored.

[0009] This Discussion of the Background section is provided for background information only. The statements in this Discussion of the Background are not an admission that the subject matter disclosed in this section constitutes prior art to the present disclosure, and no part of this Discussion of the Background section may be used as an admission that any part of this application, including this Discussion of the Background section, constitutes prior art to the present disclosure.

SUMMARY

[0010] One embodiment of the present disclosure provides a measuring apparatus of bulk viscosity. The measuring apparatus comprises a temperature-controlling cylinder having a test chamber for holding a molding material and at least one piston configured to seal an opening of the temperature-controlling cylinder. The temperature-controlling cylinder and the at least one piston are configured for measuring pressures, specific volumes and temperatures (PVT) of the molding material by applying a plurality of cooling rates to the molding material inside the testing chamber under an isobaric environment, or applying a plurality of mechanical pressures to the molding material inside the testing chamber under an isothermal environment. The measuring apparatus further includes a process module configured for deriving a plurality of parameters in relation to the pressures, specific volumes and temperatures (PVT) of the molding material based on the measurement; deriving an equilibrium pressure based on the plurality of parameters obtained from a first slowest cooling rate among the plurality of cooling rates; deriving a rate of volume change of the molding material according to the specific volumes; and deriving a bulk viscosity of the molding material at least based on the rate of volume change and the equilibrium pressure.

[0011] In some embodiments, wherein the piston is configured to change a temperature in the testing chamber and change a pressure in the testing chamber so as to provide the plurality of cooling rates and the plurality of mechanical pressures to the process module.

[0012] In some embodiments, the process module is configured to derive the equilibrium pressure by the following expression:

$$\hat{v}(\sigma,T,Q)_{PVTQ}=\hat{v}(p,T)_{equilibrium\ PVT}$$

wherein $\hat{v}$ is a specific volume, σ is a mechanical pressure, T is a temperature, Q is a cooling rate, p is the equilibrium pressure.

[0013] In some embodiments, the process module is further configured to: derive a plurality of control factors in relation to a pressure effecting on the molding material based on the first slowest cooling rate obtained from the plurality of parameters of the molding material; and derive a plurality of control factors in relation to a cooling rate effecting on the molding material.

[0014] In some embodiments, the process module derives the plurality of control factors in relation to the pressure by the following expressions:

$$(T_t)_{slow} = a_{T_t}P + b_{T_t}$$

$$(\alpha_m)_{slow} = \alpha_{m1} + (\alpha_{m0} - \alpha_{m1})(1 + (\lambda_m P)^2)^{\frac{n_m-1}{2}}$$

$$(\alpha_s)_{slow} = \alpha_{s1} + (\alpha_{s0} - \alpha_{s1})(1 + (\lambda_s P)^2)^{\frac{n_s-1}{2}}$$

$$(\hat{v}_t)_{slow} = a_{\hat{v}_t}P + b_{\hat{v}_t}$$

wherein $(T_t)_{slow}$ is a transition temperature under the first slowest cooling rate, (a_{Tt}, b_{Tt}) are control factors in relation to the pressure under the transition temperature and the first slowest cooling rate, $(\alpha_m)_{slow}$ is a volumetric coefficient of thermal expansion of the molding material in a molten state under the first slowest cooling rate, $(\alpha_{m0}, \alpha_{m1}, \lambda_m, n_m)$ are control factors in relation to the pressure effecting on the volumetric coefficient of thermal expansion in the molten state under the first slowest cooling rate, $(\alpha_s)_{slow}$ is the volumetric coefficient of thermal expansion of the molding material in a solid state under the first slowest cooling rate, $(\alpha_{s0}, \alpha_{s1}, \lambda_s, n_s)$ are control factors in relation to the pressure effecting on the volumetric coefficient of thermal expansion in the solid state under the first slowest cooling rate, $(\hat{v}_1)_{slow}$ is a specific volume at the transition temperature under the first slowest cooling rate, $(\alpha_{\hat{v}_t}, b_{\hat{v}_t})$ are control factors in relation to the pressure effecting on the specific volume at transition temperature under the first slowest cooling rate.

[0015] In some embodiments, the process module derives the plurality of control factors in relation to the cooling rate by the following expressions:

$$T_t = q_{T_t}(\ln(Q) - \ln(Q_{slow})) + (T_t)_{slow}$$

$$\alpha_m = q_{\alpha_m}(\ln(Q) - \ln(Q_{slow})) + (\alpha_m)_{slow}$$

$$\alpha_s = q_{\alpha_s}(\ln(Q) - \ln(Q_{slow})) + (\alpha_s)_{slow}$$

$$\hat{v}_t = (\hat{v}_t)_{slow} \exp\left(\int_{T_t}^{T_m}(\alpha_m)_{slow}dT - \int_{T_t}^{T_m}\alpha_m dT\right)$$

wherein q_{Tt} is the control factor in relation to the cooling rate at a transition temperature, $q_{\alpha m}$ is the control factor in relation to the cooling rate effecting on a volumetric coefficient of thermal expansion in a molten state of the molding material, $q_{\alpha s}$ is the control factor in relation to the cooling rate effecting on the volumetric coefficient of thermal expansion in a solid state of the molding material, Q_{slow} is the first slowest cooling rate, T_m is an extreme high temperature that cooling rate effect can be neglected.

[0016] In some embodiments, the process module is further configured to select a second slowest cooling rate based on the first slowest cooling rate.

[0017] In some embodiments, the second slowest cooling rate is represented by the following expression:

$$N^*Q_{slow}$$

wherein N is a number substantially smaller than 1.

[0018] In some embodiments, the number is equal to 0.1.

[0019] In some embodiments, the process module measures the bulk viscosity based on the following expression:

$$-\mu_d = \frac{\sigma - p}{\nabla \cdot u}$$

wherein σ is a mechanical pressure on the molding material, p is a calculated equilibrium pressure, and ∇·u is the rate of volume change.

[0020] In some embodiments, the process module is further configured to derive a volumetric coefficient of thermal expansion of the molding material in a solid state and a volumetric coefficient of thermal expansion of the molding material in a molten state.

[0021] In some embodiments, the process module measures the specific volume of the molding material based on the following expression:

$$\hat{v} = \hat{v}_t \exp\left(\int_{T_t}^{T}\alpha_v(T)dT\right)$$

wherein $\hat{v}_t$ is the specific volume of the molding material at a transition temperature, T is a temperature, T_t is the transition temperature of the molding material, α_v is a volumetric coefficient of thermal expansion of the molding material.

[0022] In some embodiments, the volumetric coefficient of thermal expansion of the molding material is represented by the following expression:

$$\alpha_v(T, P, Q) = \begin{cases} \alpha_m, & \text{if } T > T_t + \Delta T \\ \alpha_s + \dfrac{\alpha_m - \alpha_s}{2\Delta T}(T - (T_t - \Delta T)), & \text{if } T_t - \Delta T < T < T_t + \Delta T \\ \alpha_s, & \text{if } T < T_t - \Delta T \end{cases}$$

wherein α_v is the volumetric coefficient of thermal expansion, T is a temperature, P is a pressure, Q is a cooling rate, α_m is the volumetric coefficient of thermal expansion in the molten state, α_s is the volumetric coefficient of thermal expansion in the solid state, T_t is the transition temperature, and ΔT is a control factor of the transition state.

[0023] The foregoing has outlined rather broadly the features and technical advantages of the present disclosure in order that the detailed description of the disclosure that follows may be better understood. Additional features and advantages of the disclosure will be described hereinafter, and form the subject of the claims of the disclosure. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures or processes for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the disclosure as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Aspects of the present disclosure are best understood from the following detailed description when read

with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0025] FIG. **1** is a schematic view of an injection-molding apparatus **10** in accordance with some embodiments of the present disclosure;

[0026] FIG. **2** is a functional block diagram of the computer in FIG. **1**;

[0027] FIG. **3** is a perspective view of a measuring apparatus **300** in accordance with some embodiments of the present disclosure;

[0028] FIG. **4** is a schematic cross-sectional view of the measuring apparatus **300** of FIG. **3**;

[0029] FIG. **5** is a flow chart illustrating a method S**400** of deriving a bulk viscosity of a molding material in accordance with some embodiments of the present disclosure;

[0030] FIG. **6** is a graph showing variation of specific volumes of the molding material under various temperatures in accordance with some embodiments of the present disclosure;

[0031] FIG. **7** is a graph showing variation of specific volumetric coefficients of thermal expansion of the molding material under various temperatures in accordance with some embodiments of the present disclosure;

[0032] FIG. **8** is a graph showing variation of specific volumes of the molding material under various temperatures in accordance with some embodiments of the present disclosure;

[0033] FIG. **9** is a graph showing variation of bulk viscosities of the molding material under various temperatures with change of cooling rate in accordance with some embodiments of the present disclosure;

[0034] FIG. **10** is a graph showing variation of bulk viscosities of the molding material under various temperatures with change of mechanical pressure in accordance with some embodiments of the present disclosure; and

[0035] FIG. **11** is a graph showing variation of bulk viscosities of the molding material under rate of volume changes in accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0036] The following description of the disclosure accompanies drawings, which are incorporated in and constitute a part of this specification, and illustrate embodiments of the disclosure, but the disclosure is not limited to the embodiments. In addition, the following embodiments can be properly integrated to complete another embodiment.

[0037] References to "one embodiment," "an embodiment," "exemplary embodiment," "other embodiments," "another embodiment," etc. indicate that the embodiment(s) of the disclosure so described may include a particular feature, structure, or characteristic, but not every embodiment necessarily includes the particular feature, structure, or characteristic. Further, repeated use of the phrase "in the embodiment" does not necessarily refer to the same embodiment, although it may.

[0038] The present disclosure is directed to a method for deriving a bulk viscosity of a molding material. In order to make the present disclosure completely comprehensible, detailed steps and structures are provided in the following description. Obviously, implementation of the present disclosure does not limit special details known by persons skilled in the art. In addition, known structures and steps are not described in detail, so as not to limit the present disclosure unnecessarily. Preferred embodiments of the present disclosure will be described below in detail. However, in addition to the detailed description, the present disclosure may also be widely implemented in other embodiments. The scope of the present disclosure is not limited to the detailed description, and is defined by the claims.

[0039] The present disclosure provides a method for deriving a bulk viscosity of a molding material, wherein such method can facilitate a precise evaluation of variation of density and volume of the molding material. The bulk viscosity of the molding material can be considered during simulation. Therefore, an amount of volume change of the molding material can be accurately simulated.

[0040] FIG. **1** is a schematic view of an injection-molding apparatus **10** in accordance with some embodiments of the present disclosure. Referring to FIG. **1**, the injection-molding apparatus **10** that can be used to carry out an injection molding process includes a molding machine **20**, a mold **30**, a clamping assembly **40** and a computer **50**. The molding machine **20** includes a barrel **210** having a downstream end **212** connected to the mold **30**. The mold **30** includes mold halves **310** and **320** to define a mold cavity **330** and a runner **340** in communication with the mold cavity **330**.

[0041] The clamping assembly **40** is in operative connection with the mold **30** for clamping the mold halves **310** and **320**. In some embodiments, the clamping assembly **40** includes a fixed plate **410**, a plurality of tie bars **420** mounted on the fixed plate **410**, and a moving plate **430** slidably engaged with the tie bars **420** and guided by a driving cylinder **440**. The mold half **310** proximal to the barrel **210** is secured on the fixed plate **410**, and the mold half **320** distal to the barrel **210** is secured on the moving plate **430** in any suitable manner, wherein the driving cylinder **440** drives the moving plate **430** to open or close the mold **30**. In some embodiments, the barrel **210** includes a nozzle **2102** adapted to engage a sprue **450** in the fixed plate **410**. In some embodiments, the sprue **450** is in communication with the runner **340** as the mold half **310** is assembled with the fixed plate **410**. In some embodiments, the fixed plate **410** may be equipped with a sprue bushing **452** including the sprue **450** and receiving the nozzle **2102** during an injection time. A molding material **100** under pressure is delivered to the sprue bush **452** from the nozzle **2102** pressed tightly against the sprue bush **452** in order to deliver the molding material **100** to the sprue **450** during a filling stage of the injection time.

[0042] In some embodiments, the clamping assembly **40** further includes an ejector plate **460** mounted with at least one ejector pin (not shown), wherein the moving plate **430** is disposed between the fixed plate **410** and the ejector plate **460**. In some embodiments, the ejector plate **460** is fixed on one of the plurality of tie bars **420**. In some embodiments, the driving cylinder **440** penetrates the ejector plate **460** and directly connects to the moving plate **430** to open or close the mold **30**. After the mold halves **310** and **320** are separated (i.e., the mold **30** is opened), a distance between the moving plate **430** and the ejector plate **460** is reduced, so the ejector pin can penetrate through the ejector plate **460** to push a molded product out of the mold **30**.

[0043] A screw **220** is mounted for moving within the barrel and is operably connected, at an upstream end **214** opposite to the downstream end **212** of the barrel **210**, to a driving motor **230**. The molding machine **20** processes material, such as plastic granules **102**, by feeding the material through a hopper **240** to the barrel **210** in order to make the material soft and force the molding material **100** into the mold **30** by the use of the screw **220**, wherein the phase of the plastic granules **102** is changed from solid to liquid by at least one heater band **250** surrounding the barrel **210**. In some embodiments, the molding machine **20** further includes a check valve **260** mounted on the screw **220**, wherein the check valve **260** is in tight contact with the barrel **210** during the filling stage, and the check valve **260** is open for allowing the liquid material to flow to the downstream end **212** of the barrel **210** during a packing stage. In some embodiments, if the mold cavity **330** is almost filled with the molding material **100**, a packing process proceeds. In some embodiments, the screw **220** rotates and moves toward the upstream end **214** of the barrel **210** during the packing stage.

[0044] The injection-molding apparatus **10** further includes a controller **270** for controlling and monitoring the real-time functions of the molding machine **20**, and a display **280** for displaying data related to the performance and operation of the molding machine **20** to on-site technicians. In some embodiments, the display **280** is further configured to accept input data from the on-site technicians. In other words, the display **280** is provided with a communications link directly with the controller **270** to provide real-time control of the molding machine **20** by the on-site technicians particularly where the on-site technicians' intervention is required.

[0045] In some embodiments, the injection-molding apparatus **10** can further include operation interface communication links among the controller **270**, the display **280** and peripheral devices, and a program sequence of operation which allows the operation interface to monitor diagnostic functions of the controller **270** and the molding machine **20**, trigger sound and/or light alarms regarding conditions of the molding machine **20**, receive performance data from the molding machine **20**, and receive input data from the display **280**.

[0046] The computer **50** is associated with the molding machine **20** and is configured to execute simulation software and transmit at least one simulation result to the controller **270** through a connection such as a hard wire connection or a wireless coupling. In some embodiments, the computer **50** includes a standardized operation system capable of running general-purpose application software for assisting with the analysis of process performance data and for communicating with the controller **270** and the display **280** via communication ports of each.

[0047] FIG. **2** is a functional block diagram of the computer **50** in FIG. **1**. Referring to FIG. **2**, the computer **50** includes a processing module **510** such as a processor adapted to perform a computer-implemented simulation method for use in molding process such as injection mold and compress molding, an input/output (I/O) interface **520** electrically coupled to the processing module **510**, and memories, which may include a read-only memory (ROM) **530**, a random access memory (RAM) **540** and a storage device **550**. The ROM **530**, the RAM **540** and the storage device **550** are communicatively coupled to the processing module **510**.

[0048] The computer **50** further includes a communication port **560** associated with the controller **270** of the molding machine **20**. The computer **50** may further include one or more accompanying input/output devices including a display **570**, a keyboard **580** and one or more other input devices **590**. The input devices **590** may include a card reader, an optical disk drive or any other device that allows the computer **50** to receive input from the on-site technicians. In some embodiments, the input devices **590** are configured to input computer instructions (software algorithms) stored in a non-transitory computer-readable medium **500**, and the processing module **510** is configured to execute operations for performing a computer-implemented molding simulation method according to the computer instructions. In some embodiments, the processing module **510** reads software algorithms from the other input device **590** or the storage device **550**, executes the calculation steps, and stores the calculated result in the RAM **540**.

[0049] During the injection molding process, shrinkage rate and warpage rate are critical variables, which can be predicted from a relationship among pressure P, specific volume V, and temperature T (known as the PVT properties) of the molding material **100**. In some embodiments, prior to the performance of the injection molding process, a measuring apparatus **300** is used for obtaining the PVT properties of the molding material **100**.

[0050] FIG. **3** is a schematic perspective view of the measuring apparatus **300** in accordance with some embodiments of the present disclosure, and FIG. **4** is a schematic cross sectional view of the measuring apparatus **300**. In some embodiments, the measuring apparatus **300** is configured to measure a volumetric variation of a molding material **100** under different temperatures and pressures. In some embodiments, the measuring apparatus **300** is configured to obtain relationships among pressure P, specific volume V and temperature T (known as PVT properties) of the molding material **100**. When measuring the PVT properties of the molding material **100**, the volumetric variation of the molding material **100** is measured under isobaric or isothermal conditions provided by the measuring apparatus **300**.

[0051] In some embodiments, the measuring apparatus **300** includes a temperature-controlling cylinder **106**, an upper piston **102**, and a lower piston **108** having heating wires **113**, wherein the temperature-controlling cylinder **106** has an annular cooling channel **301** surrounding the lower piston **108**. Referring to FIG. **4**, the temperature-controlling cylinder **106**, the upper piston **102**, and the lower piston **108** can be assembled together generally along an axial direction D**1**. During a measuring process, a top opening of the temperature-controlling cylinder **106** is sealed by the upper piston **102**, and a bottom opening of the temperature-controlling cylinder **106** is sealed by the lower piston **108**.

[0052] In some embodiments, a testing chamber **110** is formed in the temperature-controlling cylinder **106**, wherein the testing chamber **110** has a longitudinal length in the axial direction D**1**. In some embodiments, the longitudinal length is measured from the top to the bottom of the testing chamber **110**, wherein the longitudinal length is the length of a space which is able to contain the molding material **100** being measured in the testing chamber **110**. In some embodiments, the testing chamber **110** is configured to contain and

keep the molding material **100** in a specific environment, for examples, an isobaric environment or an isothermal environment during the measurement process.

[0053] In some embodiments, under the measurement process, the lower piston **108** applies a pressure on the molding material **100** inside the testing chamber **110** to provide an isobaric environment, in which the pressure P is fixed, in the testing chamber **110**. Under the isobaric environment, the relationship between the specific volume V and the temperature T of the molding material **100** can be obtained by changing the temperature T in the testing chamber **110**. In some embodiments, an isothermal environment, in which the temperature T is fixed, is provided in the testing chamber **110**. Under the isothermal environment, the relationship between the specific volume V and the pressure P of the molding material **100** can be obtained by changing the pressure P with the lower piston **108**.

[0054] As discussed above, the injection molding process may be simulated prior to actual injection of the molding material. In other words, a polymeric article can be manufactured after the simulation of the injection molding process. In some embodiments, the bulk viscosity of the molding material is derived and then subsequently utilized during simulation of the injection molding process. Therefore, an amount of volume change of the molding material during the actual manufacturing can be accurately simulated.

[0055] FIG. **5** is a flow chart of a method S**400** for deriving the bulk viscosity of the molding material **100**. In some embodiments, the bulk viscosity of the molding material **100** derived by the method S**400** can be used in the injection molding process implemented by the injection molding apparatus **10** as described above or illustrated in FIGS. **1** and **2**. In some embodiments, the method S**400** comprises a step S**401** of deriving several parameters in relation to pressures, specific volumes and temperatures (PVT) of the molding material **100** under various cooling rates and various mechanical pressures; a step S**402** of deriving an equilibrium pressure based on the parameters obtained from a first slowest cooling rate among various cooling rates; a step S**403** of deriving a rate of volume change of the molding material **100**; and a step S**404** of obtaining a bulk viscosity of the molding material **100**. The following describes an exemplary process flow of the method S**400** in accordance with various embodiments of the present disclosure.

[0056] In the step S**401**, several parameters in relation to pressures, specific volumes and temperatures (PVT) of the molding material **100** under various cooling rates and various mechanical pressures are derived. In some embodiments, the parameters can be derived by a predetermined cooling approach or model. In some embodiments, the parameters are derived based on measurement of the molding material **100** under various conditions such as under various cooling rates and various mechanical pressures. In some embodiments, measurement of the molding material **100** is performed by the measuring apparatus **300** as described above or illustrated in FIGS. **3** and **4**. In some embodiments, the measuring apparatus **300** can provide various conditions for the molding material **100** during the measurement.

[0057] In some embodiments, the specific volume of the molding material **100** is measured under various conditions such as different pressures and/or different temperatures, so that the pressure-specific volume-temperature (PVT) properties of the molding material **100** can be derived based on the measurement. In some embodiments, the molding material **100** is measured under various cooling rates and/or mechanical pressures. As a result, a graph showing the PVT properties of the molding material **100** under various cooling rates and mechanical pressures is obtained.

[0058] FIG. **6** is an exemplary graph showing the PVT properties of the molding material **100** under various cooling rates and mechanical pressures. In some embodiments as shown in FIG. **6**, the PVT properties of the molding material **100** under three different cooling rates and three different mechanical pressures are obtained. As such, a total of nine solid lines can be plotted in the graph of FIG. **6**. Although only nine solid lines are plotted in the graph of FIG. **6**, it can be understood that the number of the solid lines can be adjusted as desired. Further, it can be understood that as more measurements are performed, more data can be collected and thus more solid lines can be plotted, and subsequently the bulk viscosity of the molding material **100** can be derived more accurately by the method S**400**.

[0059] In some embodiments as shown in FIG. **6**, variation of specific volumes V of the molding material **100** under various temperatures T at a predetermined cooling rate and a predetermined mechanical pressure are derived based on measurements. In some embodiments, a first group **501** of three solid lines shows the variation of the specific volume V of the molding material **100** under various temperatures T at three different cooling rates and a first mechanical pressure, a second group **502** of three solid lines shows the variation of the specific volume of the molding material **100** under various temperatures at three different cooling rates and a second mechanical pressure, and a third group **503** of three solid lines shows the variation of the specific volume of the molding material **100** under various temperatures at three different cooling rates and a third mechanical pressure.

[0060] In some embodiments, the first mechanical pressure is substantially less than the second mechanical pressure and the third mechanical pressure. In some embodiments, the third mechanical pressure is substantially greater than the first mechanical pressure and the second mechanical pressure. In some embodiments, the first mechanical pressure is the lowest pressure, and the third mechanical pressure is the highest pressure.

[0061] In some embodiments as shown in FIG. **6**, an uppermost line **501***a* of the first group **501** shows the variation of the specific volume of the molding material **100** under various temperatures at a first cooling rate and the first mechanical pressure, a middle line **501***b* of the first group **501** shows the variation of the specific volume of the molding material **100** under various temperatures at a second cooling rate and the first mechanical pressure, and a lowermost line **501***c* of the first group **501** shows the variation of the specific volume of the molding material under various temperatures at a third cooling rate and the first mechanical pressure.

[0062] In some embodiments, the first cooling rate is substantially faster than the second cooling rate and the third cooling rate. In some embodiments, the third cooling rate is substantially slower than the first cooling rate and the second cooling rate. In some embodiments, the first cooling rate is the fastest cooling, and the third cooling rate is the slowest cooling.

[0063] Similarly, the second group **502** shows the variation of the specific volume of the molding material under various temperatures at three different cooling rates and the

second mechanical pressure, and the third group **503** shows the variation of the specific volume of the molding material under various temperatures at three different cooling rates and the third mechanical pressure. In other words, an uppermost line of each group shows the variation of the specific volume of the molding material **100** under various temperatures at the fastest cooling rate, while a lowermost line of each group shows the variation of the specific volume of the molding material **100** under various temperatures at the slowest cooling rate.

[0064] Further, a graph showing volumetric coefficient of thermal expansion α_v under various temperatures can be derived from the graph showing the PVT properties of the molding material **100** under various cooling rates and mechanical pressures. In some embodiments, the volumetric coefficient of thermal expansion α_v of the molding material **100** corresponds to gradients of the variation of the specific volume of the molding materials **100**. Therefore, in some embodiments based on the graph of FIG. **6**, a total of nine graphs showing the volumetric coefficient of thermal expansion (α_v) of the molding material **100** under various temperatures can be derived.

[0065] FIG. **7** is an exemplary graph derived from one of the solid lines in the graph of FIG. **6**. In some embodiments, a solid line in the graph of FIG. **7** corresponds to gradients of one of the solid lines in the graph of FIG. **6**. In some embodiments, the solid line in the graph of FIG. **7** can be divided into three sections **601**, **602**, **603**. In some embodiments, a first section **601** represents a constant volumetric coefficient of thermal expansion of the molding material **100** in a solid state (referred as α_s), a second section **602** represents a varying volumetric coefficient of thermal expansion of the molding material **100** in a transition state, and a third section **603** represents a constant volumetric coefficient of thermal expansion of the molding material **100** in a molten state (referred as α_m).

[0066] In some embodiments, the volumetric coefficient of thermal expansion in the solid state as is substantially less than the volumetric coefficient of thermal expansion in the molten state α_m. In some embodiments, the volumetric coefficient of thermal expansion of the molding material **100** varies within a transition temperature range. In some embodiments, the transition temperature range is dependent on a control factor ΔT and therefore is defined as the transition temperature Tt plus or minus the control factor ΔT.

[0067] In some embodiments, the volumetric coefficient of thermal expansion α_v of the molding material **100** is expressed by the following equation (1):

$$\alpha_v(T, P, Q) = \begin{cases} \alpha_m, & \text{if } T > T_t + \Delta T \\ \alpha_s + \dfrac{\alpha_m - \alpha_s}{2\Delta T}(T - (T_t - \Delta T)), & \text{if } T_t - \Delta T < T < T_t + \Delta T \\ \alpha_s, & \text{if } T < T_t - \Delta T \end{cases} \quad (1)$$

where α_v is the volumetric coefficient of thermal expansion, T is temperature, P is pressure, Q is cooling rate, α_m is the volumetric coefficient of thermal expansion in the molten state, α_s is the volumetric coefficient of thermal expansion in the solid state, T_t is the transition temperature, and ΔT is a control factor of the transition state.

[0068] In some embodiments, after obtaining the volumetric coefficient of thermal expansion of the molding material **100**, the volumetric coefficient of thermal expansion of the molding material **100** is integrated, and as a result, variation of the specific volumes of the molding material **100** at various temperatures can be derived. In some embodiments, the volumetric coefficient of thermal expansion of the molding material **100** as shown in FIG. **7** is integrated to derive the specific volume ($\hat{v}$) of the molding materials **100** as shown in FIG. **8**. In some embodiments, the solid line in FIG. **8** is a continuous line.

[0069] In some embodiments, the specific volume of the molding materials **100** is expressed by the following equation (2):

$$\hat{v}=\hat{v}_t \exp\left(\int_{T_t}^{T}\alpha_v(T)dT\right) \quad (2)$$

where $\hat{v}$ is the specific volume of the molding material **100**, $\hat{v}_t$, is the specific volume at the transition temperature, T is temperature, T_t is the transition temperature of the molding material **100**, and α_v is the volumetric coefficient of thermal expansion of the molding material **100**.

[0070] Therefore, several parameters in relation to pressures, specific volumes and temperatures (PVT) of the molding material **100** under various cooling rates and various mechanical pressures are derived based on the measurement. In some embodiments, the transition temperature T_t, the specific volume at the transition temperature $\hat{v}_t$, the volumetric coefficient of thermal expansion in the solid state α_s, and the volumetric coefficient of thermal expansion in the molten state α_m are derived. In some embodiments, each of the solid lines plotted in the graph of FIG. **6** can be used to derive the transition temperature T_1, the specific volume at the transition temperature $\hat{v}_t$, the volumetric coefficient of thermal expansion in the solid state α_s, and the volumetric coefficient of thermal expansion in the molten state α_m from the graphs of FIGS. **7** and **8**.

[0071] In some embodiments, several control factors in relation to pressure effecting on the molding material **100** are derived. In some embodiments, the control factors in relation to pressure are derived based on the transition temperature T_t, the specific volume at the transition temperature $\hat{v}_t$, the volumetric coefficient of thermal expansion in the solid state α_s, and the volumetric coefficient of thermal expansion in the molten state α_m derived from the step S**401**.

[0072] In some embodiments, the transition temperature T_1, the specific volume at the transition temperature $\hat{v}_t$, the volumetric coefficient of thermal expansion in the solid state α_s, and the volumetric coefficient of thermal expansion in the molten state α_m under a first slowest cooling rate Q_{slow} are taken. In other words, the PVT properties of the molding material **100** under the first slowest cooling rate Q_{slow} are obtained. In some embodiments, the control factors in relation to pressure under the first slowest cooling rate Q_{slow} can be derived from the following set of expressions (3):

$$\begin{aligned} (T_t)_{slow} &= a_{T_t}P + b_{T_t} \\ (\alpha_m)_{slow} &= \alpha_{m1} + (\alpha_{m0} - \alpha_{m1})(1 + (\lambda_m P)^2)^{\frac{n_m-1}{2}} \\ (\alpha_s)_{slow} &= \alpha_{s1} + (\alpha_{s0} - \alpha_{s1})(1 + (\lambda_s P)^2)^{\frac{n_s-1}{2}} \\ (\hat{v}_t)_{slow} &= a_{\hat{v}_t}P + b_{\hat{v}_t} \end{aligned} \quad (3)$$

where $(T_t)_{slow}$ is the transition temperature under the first slowest cooling rate, (a_{Tt}, b_{Tt}) are control factors in relation to the pressure under the transition temperature and the first slowest cooling rate, $(\alpha_m)_{slow}$ is the volumetric coefficient of thermal expansion in the molten state under the first slowest cooling rate, $(\alpha_{m0}, \alpha_{m1}, \lambda_m, n_m)$ are control factors in relation to the pressure effecting on the volumetric coefficient of thermal expansion in the molten state under the first slowest cooling rate, $(\alpha_s)_{slow}$ is the volumetric coefficient of thermal expansion in the solid state under the first slowest cooling rate, $(\alpha_{s0}, \alpha_{s1}, \lambda_s, n_s)$ are control factors in relation to the pressure effecting on the volumetric coefficient of thermal expansion in the solid state under the first slowest cooling rate, $(\hat{v}_t)_{slow}$ is the specific volume at the transition temperature under the first slowest cooling rate, $(a_{\hat{v}_t}, b_{\hat{v}_t})$ are control factors in relation to the pressure effecting on the specific volume at the transition temperature under the first slowest cooling rate.

[0073] In some embodiments, several control factors in relation to the cooling rate effecting on the molding material **100** are derived. In some embodiments, the control factors in relation to the cooling rate are derived based on the transition temperature T_1, the specific volume at the transition temperature $\hat{v}_t$, the volumetric coefficient of thermal expansion in the solid state α_s, and the volumetric coefficient of thermal expansion in the molten state α_m derived in the step **S401**. In some embodiments, the control factors in relation to the cooling rate can be derived from the following set of expressions (4):

$$T_t = q_{T_t}(\ln(Q) - \ln(Q_{slow})) + (T_t)_{slow}$$

$$\alpha_m = q_{\alpha_m}(\ln(Q) - \ln(Q_{slow})) + (\alpha_m)_{slow}$$

$$\alpha_s = q_{\alpha_s}(\ln(Q) - \ln(Q_{slow})) + (\alpha_s)_{slow}$$

$$\hat{v}_t = (\hat{v}_t)_{slow} \exp\left(\int_{T_t}^{T_m} (\alpha_m)_{slow} dT - \int_{T_t}^{T_m} \alpha_m dT\right) \quad (4)$$

where q_{Tt} is the control factor in relation to the cooling rate at the transition temperature, $q_{\alpha m}$ is the control factor in relation to the cooling rate effecting on the volumetric coefficient of thermal expansion in the molten state, $q_{\alpha s}$ is the control factor in relation to the cooling rate effecting on the volumetric coefficient of thermal expansion in the solid state, and T_m is the extreme high temperature that cooling rate effect can be neglected (i.e. the cooling rate effect is negligible when a temperature is higher than or equal to the extreme high temperature T_m).

[0074] In some embodiments, a second slowest cooling rate is selected based on the first slowest cooling rate Q_{slow} and is defined as an equilibrium cooling rate Q_{eq}. In some embodiments, the equilibrium cooling rate Q_{eq} is represented by the following expression (5):

$$Q_{eq} N * Q_{slow} \quad (5)$$

where N is a number substantially smaller than 1.

[0075] In some embodiments, N is equal to 0.1. In some embodiments, the equilibrium cooling rate Q_{eq} is a hypothetical cooling rate based on the measurement of the molding material **100** as described above, since the equilibrium cooling rate Q_{eq} is calculated by the above expression (5) based on the first slowest cooling rate Q_{slow} obtained from the measurement.

[0076] In step **402**, an equilibrium pressure p is derived based on the parameters obtained from the first slowest cooling rate among various cooling rates. In some embodiments, the equilibrium pressure p is derived based on the parameters obtained from the second slowest cooling rate, the equilibrium cooling rate or the like. In some embodiments, the equilibrium pressure p is derived by the following expression (6):

$$\hat{v}(\sigma, T, Q)_{PVTQ} = \hat{v}(p, T)_{equilibrium\ PVT} \quad (6)$$

where $\hat{v}$ is specific volume, σ is mechanical pressure, T is temperature, Q is cooling rate, and p is equilibrium pressure.

[0077] In some embodiments, the equilibrium pressure p is derived from the specific volume under a predetermined mechanical pressure, a predetermined temperature and a predetermined cooling rate. In some embodiments, the equilibrium pressure p can be derived based on the above expression (6) and the equilibrium cooling rate Q_{eq}. In some embodiments, the equilibrium pressure p can be derived since the specific volume, the temperature and the cooling rate can be obtained based on the graphs of FIGS. **6** to **8**. In some embodiments, equilibrium PVT describes an equilibrium volume of the molding material **100**. When the molding material **100** is under a very slow cooling rate (e.g. the first slowest cooling rate Q_{slow}, the equilibrium cooling rate $Q_{eq.}$, the second slowest cooling rate, or the like), molecular chain of the molding material **100** has sufficient time to reach equilibrium state. As a result, the equilibrium volume of the molding material **100** is unrelated to a cooling rate Q. In contrast, when the molding material **100** is under a fast cooling rate Q (e.g. faster than the first slowest cooling rate Q_{slow}, the equilibrium cooling rate $Q_{eq.}$ or the second slowest cooling rate), molecular chain of the molding material **100** has insufficient time to reach equilibrium state. As a result, a disequilibrium volume of the molding material **100** is related to a cooling rate Q, and the molding material **100** is described by dynamic PVT (PVTQ).

[0078] In step **403**, a rate of volume change $\nabla \cdot u$ of the molding material **100** is derived. In some embodiments, the rate of volume change $\nabla \cdot u$ is obtained based on the specific volume obtained from the graph of FIG. **8**. In some embodiments, the rate of volume change $\nabla \cdot u$ is obtained under a predetermined specific volume and a predetermined temperature.

[0079] In step **404**, a bulk viscosity μ_d is obtained. In some embodiments, the bulk viscosity μ_d is calculated by the following expression (7):

$$-\mu_d = \frac{\sigma - p}{\nabla \cdot u} \quad (7)$$

where σ is mechanical pressure, p is a calculated equilibrium pressure, and $\nabla \cdot u$ is the rate of volume change.

[0080] After obtaining the bulk viscosity μ_d of the molding material **100**, several graphs as shown in FIGS. **9** to **11** can be plotted. FIG. **9** is a graph showing variation of the bulk viscosity under various temperatures, various cooling rates and constant mechanical pressure. In some embodiments as shown in FIG. **9**, an upper plotting **701** shows variation of the bulk viscosity under various temperatures under the second cooling rate, and a lower plotting **702** shows variation of the bulk viscosity under various temperatures under the first cooling rate faster than the second cooling rate.

[0081] In some embodiments as shown in FIG. **9**, when the temperature T is increased, the bulk viscosity is decreased. In some embodiments, when the cooling rate is

increased, the bulk viscosity is also decreased. In some embodiments, when the molding material **100** is under a lower temperature in a solid state, a mobility of molecular chains in the molding material **100** is low. As such, a resistance to a volume change is high, and thus the bulk viscosity is high. In some embodiments, when the molding material **100** is under a higher temperature in a molten state, a mobility of molecular chains in the molding material **100** is high. As such, a resistance to a volume change is low, and thus the bulk viscosity is low. In some embodiments, when the molding material **100** is under a transition temperature in a transition state, the bulk viscosity rises abruptly when the molding material **100** is changed from the molten state to the solid state.

[0082] FIG. **10** is a graph showing variation of the bulk viscosity under various temperatures, constant cooling rate and various mechanical pressures. In some embodiments as shown in FIG. **10**, an upper plotting **801** shows variation of the bulk viscosity under various temperatures and the third mechanical pressure, a middle plotting **802** shows variation of the bulk viscosity under various temperatures and the second mechanical pressure, and a lower plotting **803** shows variation of the bulk viscosity under various temperatures and the first mechanical pressure. In some embodiments, the third mechanical pressure is substantially greater than the second and the first mechanical pressures, and the second mechanical pressure is substantially greater than the first mechanical pressure.

[0083] In some embodiments as shown in FIG. **10**, when the temperature T is increased, the bulk viscosity is decreased. In some embodiments, when the mechanical pressure is increased, the bulk viscosity is also increased. In some embodiments, when the molding material **100** is under a lower temperature in a solid state, the bulk viscosity is high. In some embodiments, when the molding material **100** is under a higher temperature in a molten state, the bulk viscosity is low. In some embodiments, when the molding material **100** is under a transition temperature in a transition state, the bulk viscosity rises abruptly when the molding material **100** is changed from the molten state to the solid state.

[0084] FIG. **11** is a graph showing variation of the bulk viscosity pa under various rates of volume change $\nabla \cdot u$, constant temperature and constant mechanical pressure. In some embodiments as shown in FIG. **10**, when the rate of volume change is increased, the bulk viscosity is decreased. In some embodiments, the bulk viscosity pa obtained from the step S**407** or the graph of FIG. **9** or the graph of FIG. **10** can be used for further calculation or simulation.

[0085] In conclusion, a bulk viscosity of the molding material **100** can be derived. The bulk viscosity describes an irreversible resistance to a change of volume of the molding material **100**. As such, variation of density or volume of the molding material **100** can be accurately evaluated. Therefore, the molding material **100** can be accurately simulated based on the bulk viscosity.

[0086] In summary, the present disclosure provides a method for deriving a bulk viscosity of a molding material. The method comprises: deriving a plurality of parameters in relation to physical properties of the molding material; deriving a plurality of control factors in relation to a pressure effecting on the molding material based on a first slowest cooling rate obtained from the plurality of parameters of the molding material; deriving a plurality of control factors in relation to a cooling rate effecting on the molding material; selecting a second slowest cooling rate based on the first slowest cooling rate; deriving an equilibrium pressure from the second slowest cooling rate; deriving a rate of volume change; and obtaining the bulk viscosity of the molding material based on the rate of volume change.

[0087] One aspect of the present disclosure provides a measuring apparatus including a testing chamber, a temperature-controlling cylinder, a piston, and a process module. The testing chamber is configured to hold a molding material. The temperature-controlling cylinder is configured to form the testing chamber. The piston is configured to seal an opening of the temperature-controlling cylinder. The process module is configured to measure a bulk viscosity of the molding material by applying a plurality of cooling rates to the molding material inside the testing chamber under an isobaric environment, or applying a plurality of mechanical pressures to the molding material inside the testing chamber under an isothermal environment; measuring pressures, specific volumes and temperatures (PVT) of the molding material under the plurality of cooling rates and the plurality of mechanical pressures; deriving a plurality of parameters in relation to the pressures, specific volumes and temperatures (PVT) of the molding material based on the measurement; deriving an equilibrium pressure based on the plurality of parameters obtained from a first slowest cooling rate among the plurality of cooling rates; deriving a rate of volume change of the molding material according to the specific volumes; and obtaining the bulk viscosity of the molding material based on the rate of volume change and the equilibrium pressure.

[0088] Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the appended claims. For example, many of the processes discussed above can be implemented in different methodologies and replaced by other processes, or a combination thereof.

[0089] Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A measuring apparatus, comprising:

a temperature-controlling cylinder having a test chamber for holding a molding material;

at least one piston, configured to seal an opening of the temperature-controlling cylinder; and

wherein the temperature-controlling cylinder and the at least one piston are configured for measuring pressures, specific volumes and temperatures (PVT) of the molding material by applying a plurality of cooling rates to

the molding material inside the testing chamber under an isobaric environment, or applying a plurality of mechanical pressures to the molding material inside the testing chamber under an isothermal environment;

a process module configured for deriving a plurality of parameters in relation to the pressures, specific volumes and temperatures (PVT) of the molding material based on the measurement; deriving an equilibrium pressure based on the plurality of parameters obtained from a first slowest cooling rate among the plurality of cooling rates; deriving a rate of volume change of the molding material according to the specific volumes; and deriving a bulk viscosity of the molding material at least based on the rate of volume change and the equilibrium pressure.

2. The measuring apparatus of claim **1**, wherein the at least one piston is configured to change a temperature in the testing chamber and change a pressure in the testing chamber so as to apply the plurality of cooling rates and the plurality of mechanical pressures to the molding material.

3. The measuring apparatus of claim **1**, wherein the process module is configured to derive the equilibrium pressure by the following expression:

$$\hat{v}(\sigma,T,Q)_{PVTQ}=\hat{v}(p,T)_{equilibrium\ PVT}$$

wherein $\hat{v}$ represents the specific volumes, σ represents the mechanical pressures, T represents the temperatures, Q represents the cooling rates, p represents the equilibrium pressure.

4. The measuring apparatus of claim **1**, wherein the process module is further configured to:

derive a plurality of control factors in relation to a pressure effecting on the molding material based on the first slowest cooling rate obtained from the plurality of parameters of the molding material; and

derive a plurality of control factors in relation to a cooling rate effecting on the molding material.

5. The measuring apparatus of claim **4**, wherein the process module derives the plurality of control factors in relation to the pressure by the following expressions:

$$(T_t)_{slow} = a_{T_t} P + b_{T_t}$$

$$(\alpha_m)_{slow} = \alpha_{m1} + (\alpha_{m0} - \alpha_{m1})(1 + (\lambda_m P)^2)^{\frac{n_m-1}{2}}$$

$$(\alpha_s)_{slow} = \alpha_{s1} + (\alpha_{s0} - \alpha_{s1})(1 + (\lambda_s P)^2)^{\frac{n_s-1}{2}}$$

$$(\hat{v}_t)_{slow} = a_{\hat{v}_t} P + b_{\hat{v}_t}$$

wherein $(T_t)_{slow}$ is a transition temperature under the first slowest cooling rate, (a_{Tt}, b_{Tt}) are control factors in relation to the pressure under the transition temperature and the first slowest cooling rate, $(\alpha_m)_{slow}$ is a volumetric coefficient of thermal expansion of the molding material in a molten state under the first slowest cooling rate, $(\alpha_{m0}, \alpha_{m1}, \lambda_m, n_m)$ are control factors in relation to the pressure effecting on the volumetric coefficient of thermal expansion in the molten state under the first slowest cooling rate, $(\alpha_s)_{slow}$ is the volumetric coefficient of thermal expansion of the molding material in a solid state under the first slowest cooling rate, $(\alpha_{s0}, \alpha_{s1}, \lambda_s, n_s)$ are control factors in relation to the pressure effecting on the volumetric coefficient of thermal expansion in the solid state under the first slowest cooling rate, $(\hat{v}_t)_{slow}$ is a specific volume at the transition temperature under the first slowest cooling rate, $(a_{\hat{v}_t}, b_{\hat{v}_t})$ are control factors in relation to the pressure effecting on the specific volume at transition temperature under the first slowest cooling rate.

6. The measuring apparatus of claim **4**, wherein the process module derives the plurality of control factors in relation to the cooling rate by the following expressions:

$$T_t=q_{T_t}(\ln(Q)-\ln(Q_{slow}))+(T_t)_{slow}$$

$$\alpha_m=q_{\alpha_m}(\ln(Q)-\ln(Q_{slow}))+(\alpha_m)_{slow}$$

$$\alpha_s=q_{\alpha_s}(\ln(Q)-\ln(Q_{slow}))+(\alpha_s)_{slow}$$

$$\hat{v}_t=(\hat{v}_t)_{slow}\exp(\int_{T_t}^{T_m}(\alpha_m)_{slow}dT-\int_{T_t}^{T_m}\alpha_m dT)$$

wherein q_{Tt} is the control factor in relation to the cooling rate at a transition temperature, $q_{\alpha m}$ is the control factor in relation to the cooling rate effecting on a volumetric coefficient of thermal expansion in a molten state of the molding material, $q_{\alpha s}$ is the control factor in relation to the cooling rate effecting on the volumetric coefficient of thermal expansion in a solid state of the molding material, Q_{slow} is the first slowest cooling rate, T_m is an extreme high temperature that cooling rate effect can be neglected.

7. The measuring apparatus of claim **4**, wherein the process module is further configured to select a second slowest cooling rate based on the first slowest cooling rate.

8. The measuring apparatus of claim **7**, wherein the second slowest cooling rate is represented by the following expression:

$$N*Q_{slow}$$

wherein N is a number substantially smaller than 1.

9. The measuring apparatus of claim **8**, wherein the number is equal to 0.1.

10. The measuring apparatus of claim **1**, wherein the process module derives the bulk viscosity based on the following expression:

$$-\mu_d = \frac{\sigma - p}{\nabla \cdot u}$$

wherein σ is a mechanical pressure applied to the molding material, p is a calculated equilibrium pressure, and ∇·u is the rate of volume change.

11. The measuring apparatus of claim **1**, wherein the process module is further configured to derive a volumetric coefficient of thermal expansion of the molding material in a solid state and a volumetric coefficient of thermal expansion of the molding material in a molten state.

12. The measuring apparatus of claim **1**, wherein the process module derives the specific volume of the molding material based on the following expression:

$$\hat{v}=\hat{v}_t\exp(\int_{T_t}^{T}\alpha_v(T)dT)$$

wherein $\hat{v}_t$ is the specific volume of the molding material at a transition temperature, T is a temperature, T_t is the transition temperature of the molding material, α_v is a volumetric coefficient of thermal expansion of the molding material.

13. The measuring apparatus of claim **12**, wherein the volumetric coefficient of thermal expansion of the molding material is represented by the following expression:

$$\alpha_v(T, P, Q) = \begin{cases} \alpha_m, \text{ if } T > T_t + \Delta T \\ \alpha_s + \dfrac{\alpha_m - \alpha_s}{2\Delta T}(T - (T_t - \Delta T)), \text{ if } T_t - \Delta T < T < T_t + \Delta T \\ \alpha_s, \text{ if } T < T_t - \Delta T \end{cases}$$

wherein α_v is the volumetric coefficient of thermal expansion, T is a temperature, P is a pressure, Q is a cooling rate, α_m is the volumetric coefficient of thermal expansion in the molten state, α_s is the volumetric coefficient of thermal expansion in the solid state, T_t is the transition temperature, and ΔT is a control factor of the transition state.

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