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United States Patent	12385931
Kind Code	B2
Date of Patent	August 12, 2025
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Biological sample analyzer with accelerated thermal warming

Abstract

In one embodiment, a biological sample analyzer has a housing having at least one outer wall that defines a cavity therein. A receptacle, which can support a consumable holder containing a biological sample, is disposed within the cavity. At least one heater applies heat to the consumable holder when the consumable holder is supported by the receptacle. At least one heater sensor detects a temperature of the receptacle over time. A controller directs the at least one heater to apply an elevated temperature to the consumable holder and reduces an amount of heat applied to the consumable holder before the consumable holder exceeds a target temperature that is less than the elevated temperature. By applying the elevated temperature, the consumable holder can be heated quicker than if it where heated at only the target temperature.

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Appl. No.:	**17/593482**
Filed (or PCT Filed):	**March 16, 2020**
PCT No.:	**PCT/US2020/022914**
PCT Pub. No.:	**WO2020/197815**
PCT Pub. Date:	October 01, 2020

Prior Publication Data

Document Identifier	**Publication Date**
US 20220221475 A1	Jul. 14, 2022

Related U.S. Application Data

us-provisional-application US 62822379 20190322

Publication Classification

Int. Cl.: **G01N11/00** (20060101); **B01L7/00** (20060101); **G01N35/00** (20060101)

U.S. Cl.:

CPC **G01N35/00029** (20130101); **B01L7/00** (20130101); B01L2200/147 (20130101); G01N2035/00366 (20130101); G01N2035/00376 (20130101)

Field of Classification Search

CPC: B01L (7/52); B01L (2200/147)

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Background/Summary

(1) This application claims priority to U.S. Provisional Application No. 62/822,379, filed Mar. 22, 2019, the disclosure of which is incorporated herein by reference in its entirety.

CROSS-REFERENCE TO RELATED CASES

(1) This application is related to U.S. patent application Ser. No. 62/822,371, filed on the same date as the present application, and U.S. patent application Ser. No. 62/822,391, filed on the same date as the present application, the teachings of both of which are hereby incorporated by reference as if set forth in their entirety herein.

TECHNICAL FIELD

(2) This disclosure generally relates to biological sample analyzers, and more particularly to heating of consumable biological sample holders used in biological sample analyzers.

BACKGROUND

(3) In point-of-care services, a benchtop biological sample analyzer is commonly used to analyze biological samples of patients such as blood and urine. Typically, the biological sample is fed into a cartridge having a reagent therein. The cartridge is inserted into the analyzer, and the analyzer moves the cartridge so as to mix the sample with the reagent. Further, the analyzer heats the sample and reagent a target temperature, typically above room temperature, and then analyzes the heated sample.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The foregoing summary, as well as the following detailed description, will be better understood when read in conjunction with the appended drawings. The drawings show illustrative embodiments of the disclosure. It should be understood, however, that the application is not limited to the precise arrangements and instrumentalities shown.

(2) FIG. **1** shows a top perspective view of a biological sample analyzer according to an illustrative embodiment of the present disclosure;

(3) FIG. **2** shows a bottom perspective view of the biological sample analyzer shown in FIG. **1**;

(4) FIG. **3** shows a perspective view of interior components of the biological sample analyzer of FIG. **1**, including an air plenum, a motor, a diagnostic consumable holder, and a receptacle for the diagnostic consumable holder;

(5) FIG. **4** shows a cross-sectional view of the biological sample analyzer of FIG. **1**, taken along a center line that extends from the front to the back of the biological sample analyzer in FIG. **1**;

(6) FIG. **5** shows a cross-sectional view of the biological sample analyzer of FIG. **1**, taken along line **5-5** shown in FIG. **4** and with the housing removed;

(7) FIG. **6** shows the cross-sectional view of the biological sample analyzer of FIG. **4** with the housing removed;

(8) FIG. **7** shows an exploded perspective view of the receptacle and consumable holder of the biological sample analyzer of FIG. **1**;

(9) FIG. **8** shows an alternative exploded perspective view of the receptacle and consumable holder of the biological sample analyzer of FIG. **1**;

(10) FIG. **9** shows a simplified flow diagram of a method of heating a biological sample to a target temperature;

(11) FIG. **10** shows a simplified flow diagram of a method of detecting a cold consumable holder and compensating for the cold consumable holder;

(12) FIG. **11** shows a simplified flow diagram of a method of operating a fan of the biological sample analyzer;

(13) FIG. **12** shows a graphical representation of the temperature of heaters of the biological sample analyzer of FIG. **1** over time during a heating operation of the consumable holder; and

(14) FIG. **13** shows a graphical representation of the speed of a fan of the biological sample analyzer of FIG. **1** over time during a heating operation of the consumable holder.

DETAILED DESCRIPTION

(15) In a conventional biological sample analyzer, the heaters of the analyzer are set to apply a target temperature to a diagnostic consumable holder such as a cartridge, card, or cassette, that holds a biological sample and reagent. The target temperature corresponds to the temperature at which the biological sample will be analyzed, and is typically above an ambient or room temperature. The diagnostic consumable holder is then permitted to reach the target temperature. However, heating the diagnostic consumable holder in such a manner can be time consuming, thereby delaying the time needed to obtain an analysis of the sample. Therefore, there is a desire to reduce the amount of time needed to heat the diagnostic consumable holder to the target temperature. One method of reducing the amount of time needed is to redesign the diagnostic consumable holder to have a smaller mass, which will heat quicker at a given temperature than a diagnostic consumable holder having a larger mass. However, redesigning the diagnostic consumable holder can render any unused diagnostic consumable holders obsolete, and can also necessitate a redesign of the biological sample analyzer.

(16) As an alternative, the biological sample analyzer can be configured to accelerate heating of the diagnostic consumable holder by setting at least one heater of the analyzer to apply an elevated temperature that is greater than the target temperature. In some embodiments, the elevated temperature can correspond to a maximum heating capability of the at least one heater. However, care should be taken to not overheat the diagnostic consumable holder beyond the target temperature. Therefore, the biological sample analyzer can be configured to rapidly cool the at least one heater before the diagnostic consumable holder exceeds the target temperature. As described below, this can be accomplished, at least in part, by reducing the heating applied by the at least one heater. Additionally or alternatively, rapid cooling can be accomplished by causing a fan to force air over the at least one heater of the sample analyzer at a determined time before the diagnostic consumable holder exceeds the target temperature so as to cool the at least one heater to the target temperature. The fan can be operated at a first speed when the at least one heater is heating to the elevated temperature, and can be operated at a second speed that is faster than the first speed, when the heater is heating to the target temperature. The first speed can be zero or greater than zero, and thus, the fan can be moving or can be off when at the first speed. The air from the fan can be directed over the heaters through a plenum disposed within the sample analyzer.

(17) A diagnostic consumable holder may have a relatively short shelf life (e.g., approximately eight weeks) when kept at room temperature. This may be due at least in part to the shelf life of a reagent held or contained in the diagnostic consumable holder. Therefore, the diagnostic consumable holder can be refrigerated so as to extend the shelf life of the diagnostic consumable holder (e.g., to approximately two years). However, conventional biological sample analyzers typically do not account for the lowered temperature of a refrigerated diagnostic consumable holder. As a result, the diagnostic consumable holder must be removed from the refrigerator for a period of time (e.g., ½ hour) prior to being inserted into a conventional biological sample analyzer so as to bring the diagnostic consumable holder to room temperature.

(18) If the diagnostic consumable holder is not brought to room temperature, then the analyzer might not heat the diagnostic consumable holder to the target temperature. This can result in a bias or error in the analyzed results generated by the biological sample analyzer because the analysis is temperature sensitive. Alternatively, the analyzer might reject the diagnostic consumable holder, and as a result, the operator would need to obtain a new sample from the patient thereby resulting in delay. As described below, a sample analyzer of the present disclosure can be configured to detect a diagnostic consumable holder that has been refrigerated and inserted into the sample analyzer before the diagnostic consumable holder has warmed to an ambient temperature range (herein referred to as a “cold consumable holder”). As used herein, the term “cold consumable holder” is used to refer to a consumable holder that is below an ambient temperature range. In one embodiment, the ambient temperature range can be from about 15 degrees Celsius to about 32

degrees Celsius. In another embodiment, the ambient temperature range is a room temperature range of from about 20 degrees Celsius to about 25 degrees Celsius. The sample analyzer can further be configured to adjust heating of the diagnostic consumable holder so as to bring the diagnostic consumable holder to the target temperature before the sample is analyzed by the sample analyzer.

(19) Described herein is a biological sample analyzer **10** that includes a receptacle **154** configured to receive a diagnostic consumable holder **162** with a biological sample disposed therein. In the figures, the diagnostic consumable holder **162** is shown as a cartridge; however, the diagnostic consumable holder **162** can be a cartridge, card, cassette, or any other suitable housing configured to retain a biological sample therein for analysis. At least one heater **186** is attached to the receptacle **154**, and is configured to heat the receptacle **154**. At least one heater sensor **188** is attached to the receptacle **154**, and is configured to detect an instantaneous temperature of the receptacle **154**. Certain terminology is used to describe the biological sample analyzer **10** in the following description for convenience only and is not limiting. The words “lower” and “upper” designate directions with respect to the orientation shown in the drawings. The words “inner” and “outer” refer to directions toward and away from, respectively, the geometric center of the part being described.

(20) Unless otherwise specified herein, the terms “longitudinal,” “lateral,” and “vertical” and are used to describe the orthogonal directional components of various components of the biological sample analyzer **10**, as designated by the first direction D.sub.1, second direction D.sub.2, and third direction D.sub.3. It should be appreciated that while the first and second directions D.sub.1, D.sub.2 are illustrated as extending along a horizontal plane, and the third direction D.sub.3 is illustrated as extending along a vertical plane, the planes that encompass the various directions may differ during use.

(21) Referring to FIGS. **1** and **2**, a biological sample analyzer **10** is shown that is configured to heat a diagnostic consumable holder **162** containing a biological sample and a reagent, and measure a characteristic of the heated biological sample. The biological sample analyzer **10** can be configured to accelerate heating of the consumable holder **162** by setting at least one heater of the analyzer to apply an elevated temperature that is above the target temperature of the biological sample. The biological sample analyzer **10** can include a housing **14** configured to house various components of the biological sample analyzer **10**. The housing **14** can include at least one outer wall **18**. The at least one outer wall has an outer surface, and an inner surface opposite the outer surface. The at least one outer wall **18**, such as the inner surface of the at least one outer wall **18**, defines an internal cavity **34** of the housing **14** that is configured to house various components for heating and measuring characteristics of the biological sample.

(22) The housing **14** can have a first end **14***a* and a second end **14***b* that are spaced from one another along a first direction D.sub.1. The housing **14** can have a first side **14***c* and a second side **14***c* that are spaced from one another along a second direction D.sub.2, perpendicular to the first direction D.sub.1. The housing **14** can define an upper end **14***e* and a lower end **14***f* that are spaced from one another along a third direction D.sub.3, perpendicular to both the first and second directions D.sub.1 and D.sub.2. The internal cavity **34** can be defined between the first and second ends **14***a* and **14***b*, between the first and second sides **14***c* and **14***d*, and between the upper and lower ends **14***e* and **14***f*.

(23) The at least one outer wall **18** can define a plurality of outer walls. For example, the at least one outer wall **18** can include a first wall **18***a* at the first end **14***a*. The at least one outer wall **18** can include a second end wall **18***b* at second end **14***b*. The at least one outer wall **18** can include a first sidewall **18***c* at the first side **14***c*. The at least one outer wall **18** can include a second sidewall **18***d* at the second side **14***d*. The at least one outer wall **18** can include an upper wall **18***e* at the upper end **14***e*. The at least one outer wall **18** can include a lower wall **18***f* at the lower end **14***f* It will be understood that the housing **14** can have any suitable shape, including shapes other than that

shown, that defines a cavity therein. Accordingly, the at least one outer wall **18** can include as few as a single wall (e.g., in the event that the housing **14** has a spherical shape) or more than one wall, and the walls can have a shape other than that shown.

(24) The at least one outer wall **18** defines an opening **22** that extends therethrough. The opening **22** is open to the cavity **34** such that the opening **22** is configured to receive the consumable holder **162 162** into the cavity **34**. The opening **22** can extend into the upper end **14***e* of the housing **14**, such as into the upper wall **18***e*. However, it will be understood that, in alternative embodiments, the opening **22** can extend into one or more of the end **14***a*, end **14***b*, side **14***c*, side **14***d*, and end **14***e*.

(25) The biological sample analyzer **10** can include a door **26** that is movably coupled to the housing **14**. The door **26** can be configured to selectively cover the opening **22** so as to prevent heat from escaping the biological sample analyzer **10** through the opening **22**. The door **26** is configured to be transitioned between an open position, where the housing **14** is configured to receive the consumable holder **162** through the opening **22**, and a closed position, where the door **26** covers the opening **22**. In the closed position, the door **26** both prevents a consumable holder **162** from being inserted into the biological sample analyzer **10** through the opening **22**, and prevents a consumable holder **162** already disposed within the internal cavity **34** from being removed from the biological sample analyzer **10**. The biological sample analyzer **10** can include a door sensor **30** configured to detect whether the door **26** is in the open position or the closed position. The door sensor **30** can be, for example, a relay switch or any other suitable sensor that can detect when a door is open or closed.

(26) The door sensor **30** can be in signal communication with a controller **46**. The controller **46**, which can be a PID controller, can comprise any suitable computing device configured to host a software application for monitoring and controlling various operations of the biological sample analyzer **10** as described herein. It will be understood that the controller **46** can include any appropriate computing device, examples of which include a processor, a desktop computing device, a server computing device, or a portable computing device, such as a laptop, tablet, or smart phone. The controller **46** can be physically attached to the housing, disposed within the housing **14**, or can be remote to and potentially spaced a distance from the housing **14**.

(27) The controller **46** can include a memory **50**. The memory **50** can be volatile (such as some types of RAM), non-volatile (such as ROM, flash memory, etc.), or a combination thereof. The controller **46** can include additional storage (e.g., removable storage and/or non-removable storage) including, but not limited to, tape, flash memory, smart cards, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic tape, magnetic disk storage or other magnetic storage devices, universal serial bus (USB) compatible memory, or any other medium which can be used to store information and which can be accessed by the controller **46**.

(28) The controller **46** can optionally include a human-machine interface (HMI) device **54**. The HMI device **54** can include inputs that provide the ability to control the controller **46**, via, for example, buttons, soft keys, a mouse, voice actuated controls, a touch screen, movement of the controller **46**, visual cues (e.g., moving a hand in front of a camera on the controller **46**), or the like. The HMI device **54** can provide outputs, via a graphical user interface, including visual information concerning various components of the biological sample analyzer **10**. Other outputs can include audio information (e.g., via speaker), mechanically (e.g., via a vibrating mechanism), or a combination thereof. In various configurations, the HMI device **54** can include a display, a touch screen, a keyboard, a mouse, a motion detector, a speaker, a microphone, a camera, or any combination thereof. The HMI device **54** can include any suitable device for inputting biometric information, such as, for example, fingerprint information, retinal information, voice information, and/or facial characteristic information, for instance, so as to require specific biometric information for accessing the controller **46**.

(29) The controller **46** can be in wired and/or wireless communication with the door sensor **30**, as

well as various other components of the biological sample analyzer **10**, as will be described further below. The controller **46**, and specifically the HMI device **54**, can be configured to produce an alert if the door sensor **30** senses that the door **26** is in the open position for a predetermined amount of time. In one embodiment, the predetermined amount of time can be about 15 seconds. However, it is contemplated that the predetermined amount of time can be more or less than 15 seconds as desired. Optionally, the HMI device **54** can be configured to receive a user input such that an operator of the biological sample analyzer **10** can manually select and/or adjust the predetermined amount of time that the door **26** can be in the open position. When the door **26** is maintained in the open position for the predetermined amount of time after a consumable holder **162** is disposed within the housing **14**, the controller **46** may invalidate the intended heating operation and produce a corresponding alert via the HMI device **54**.

(30) Referring to FIG. **2**, the at least one outer wall **18** of the housing **14** can define an air intake **38** that extends through the at least one outer wall **18**. The air intake **38** is configured to receive air from outside the housing **14** and into the internal cavity **34**. The air intake **38** can be defined by at least one opening that extends through the at least one outer wall **18**, such as a plurality of openings spaced about the at least one outer wall **18**. The air intake **38** can extend through a first wall of the at least one of the outer wall **118**. In FIG. **2**, the air intake **38** is defined at the second end **18***b*, and in particular, is defined by the second end wall **18***b*. Further, the air intake **38** is oriented substantially along a plane that is parallel to the second and third directions D.sub.2, D.sub.3, e.g., a substantially vertically-oriented plane. However, it will be understood that the air intake **38** can be defined at any another side or end of the housing **14**, and can be oriented along a different plane or multiple planes.

(31) The at least one outer wall **18** of the housing **14** can define an air exhaust **42** that extends through the at least one outer wall **18**. The air exhaust **42** is spaced from the air intake **38** about the at least one outer wall **18**. The air exhaust **42** can extend through a second wall of the at least one of the outer wall **118**. The second outer wall can be different from the first outer wall through which the air intake **38** extends. In some embodiments, the second outer wall can be angularly offset from the first outer wall. The air exhaust **42** is configured to expel air from the internal cavity **34** to an area outside of the housing **14**. Like the air intake **38**, the air exhaust **42** can be defined by at least one opening that extends through the at least one outer wall **18**, such as a plurality of openings spaced about the at least one outer wall **18**. In FIG. **2**, the air exhaust **42** is defined at the lower end **18***f* of the housing **14**, and in particular, is defined by the lower end wall **18***f*. Further, the air exhaust **42** is oriented substantially along a plane that is parallel to the first and second directions D.sub.1, D.sub.2, e.g., a substantially horizontally-oriented plane. As a result, the air intake **38** can be angularly offset from the air exhaust **42**. In the depicted embodiment, the air intake **38** is angularly offset from the air exhaust **42** by about 90 degrees. However, the air intake **38** and the air exhaust **42** can be alternatively oriented relative to each other as desired. It will be understood that the air exhaust **42** can be defined at any another side or end of the housing **14**, and can be oriented along a different plane or multiple planes.

(32) The air intake **38** can be configured to provide received air into the internal cavity **34** along an intake direction D.sub.I. The air exhaust **42** can be configured to receive air from the cavity **34** along an exhaust direction D.sub.E, and to expel the air out of the cavity **34**. The intake direction D.sub.I can be angularly offset from the exhaust direction D.sub.E. In one example, the intake direction D.sub.I can be substantially perpendicular to the exhaust direction D.sub.E. In alternative embodiments, the intake direction D.sub.I and exhaust direction D.sub.E can be substantially parallel to one another. In some embodiments, the air intake **38** can receive the air along the intake direction D.sub.I. Additionally or alternatively, in some embodiments, the air exhaust **42** can expel air along the exhaust direction D.sub.E. However, it will be understood that in alternative embodiments, at least one of the air intake **38** and air exhaust **42** can include louvers that changes the trajectory of the air as it is received into the air intake **38** or expelled from the air exhaust **42**.

(33) Turning to FIG. **3**, the biological sample analyzer **10** includes a plenum **100** disposed within the internal cavity **34** of the housing **14**. The plenum **100** can include at least one plenum wall **104** that has an inner plenum surface, and an outer plenum surface opposite the inner surface. The at least one plenum wall **104**, such as the inner surface of the at least one plenum wall **104**, defines an air duct **120** therein. The plenum **100** can have a first plenum end **100***a* and a second plenum end **100***b* that are spaced from one another along a first direction D.sub.1. The plenum **100** can have a first plenum side **100***c* and a second plenum side **100***c* that are spaced from one another along the second direction D.sub.2. The plenum **100** can define an upper plenum end **100***e* and a lower plenum end **100***f* that are spaced from one another along the third direction D.sub.3. The air duct **120** can be defined between the first and second plenum ends **100***a* and **100***b*, between the first and second plenum sides **100***c* and **100***d*, and between the upper and lower plenum ends **100***e* and **100***f*.
(34) The at least one plenum wall **104** can include a plurality of plenum walls. For example, the at least one plenum wall **104** can include a first plenum end wall **104***a* at the first plenum end **100***a*. The at least one plenum wall **104** can include a second plenum end wall **104***b* at the second plenum end **100***b*. The at least one plenum wall **104** can include a first plenum sidewall **104***c* at the first plenum side **100***c*. The at least one plenum wall **104** can include a fourth plenum wall **104***d* at the second plenum side **100***d*. The at least one plenum wall **104** can include an upper plenum wall **110***e* at the upper plenum end **100***e*. The at least one plenum wall **100** can include a lower plenum wall **104***f* at the lower plenum end **100***f*. It will be understood that the plenum **100** can have any suitable shape, including shapes other than that shown. Accordingly, the at least one outer plenum wall **104** can include as few as a single wall or more than one wall, and the walls can have a shape other than that shown.
(35) The at least one plenum wall **104** can define an opening **108** that extends therethrough. The opening **108** is open to the air duct **120** such that the opening **108** is configured to receive the consumable holder **162** into the air duct **120**. The opening **108** is aligned below the opening **22** of the housing **14** such that a straight path is defined from the opening **22** of housing **14** into the air duct **120** through the opening **108**. The opening **108** can extend into the upper end **100***e* of the plenum **100**, such as into the upper plenum wall **104***e*. However, it will be understood that, in alternative embodiments, the opening **108** can extend into one or more of the end **100***a*, end **100***b*, side **100***c*, side **100***d*, and end **100***e*.
(36) The plenum **100** defines a plenum intake **112** that extends through the at least one plenum wall **104**. The plenum intake **112** is configured to receive air from the air intake **38** of the housing **14** into the plenum **100**. The plenum intake **112** is disposed adjacent to, and is in fluid communication with, the air intake **38** such that air received at the air intake **38** is received into the plenum intake **112**. The plenum intake **112** can be defined by at least one opening, or a plurality of openings spaced about the at least one plenum wall **104**. In FIG. **3**, the plenum intake **112** is defined at the second plenum end **100***b*, and in particular, is defined by the second plenum end wall **104***b*. Further, the plenum intake **112** is oriented substantially along a plane that is parallel to the second and third direction D.sub.2, D.sub.3, e.g., a substantially vertically-oriented plane. However, it will be understood that the plenum intake **112** can be defined at any another side or end of the plenum **100**, and can be oriented along a different plane or multiple planes.
(37) The plenum **100** defines a plenum exhaust **116** that extends through the at least one plenum wall **104**. The plenum exhaust **116** is spaced from the plenum intake **112** about the at least one plenum wall **104** such that the air duct **120** extends from the plenum exhaust **116** to the plenum intake **112**. The plenum exhaust **116** is configured to expel air from the plenum **100**. The plenum exhaust **116** is disposed adjacent to, and is in fluid communication with, the air exhaust **42** such that air expelled from the plenum exhaust **116** is expelled out of the air exhaust **42**. Like the plenum intake **112**, the plenum exhaust **116** can be defined by at least one opening, or a plurality of openings spaced about the plenum wall **104**. In FIG. **3**, the plenum exhaust **116** is defined at the lower plenum end **100***f*, and in particular, is defined by the lower plenum end wall **104***f*. Further,

the plenum exhaust **116** is oriented substantially along a plane that is parallel to the first and second directions D.sub.1, D.sub.2, e.g., a substantially horizontally-oriented plane. As a result, the plenum intake **112** can be angularly offset from the plenum exhaust **116**. In the depicted embodiment, the plenum intake **112** is angularly offset from the plenum exhaust **116** by 90 degrees. However, the plenum intake **112** and the plenum exhaust **116** can be angularly offset from one another by any other suitable angle. In alternative embodiments, the plenum exhaust **112** and the plenum intake **116** can be parallel to one another. It will be understood that the plenum exhaust **116** can be defined at any another side or end of the plenum **100**, and can be oriented along a different plane or multiple planes.

(38) The plenum intake **112** can be configured to receive air into the air duct **120** along the intake direction D.sub.I. The plenum exhaust **116** can be configured to expel air along the exhaust direction D.sub.E. As described above, the intake direction D.sub.I can be angularly offset from the exhaust direction D.sub.E. In one example, the intake direction D.sub.I can be substantially perpendicular to the exhaust direction D.sub.E. In alternative embodiments, the intake direction D.sub.I and exhaust direction D.sub.E can be substantially parallel to one another. In operation, the biological sample analyzer **10** is configured to receive air through the air intake **38** of the housing **14**, through the plenum intake **112**, through the air duct **120**, out of the air duct **120** through the plenum exhaust **116**, and out of the housing **14** through the air exhaust **42**.

(39) Now referring to FIGS. **4**, **7**, and **8**, the biological sample analyzer **10** comprises a receptacle **154** that is configured to support the consumable holder **162** containing the biological sample. At least a portion of the receptacle **154** is disposed within the plenum **100**. The receptacle **154** can have an open end configured to receive and hold the consumable holder **162** during a heating and measuring operation. The receptacle can have a substantially rectangular shape; however, the shape of the receptacle **154** can vary depending on the shape of the consumable holder to be received.

(40) In the depicted embodiment, the receptacle **154** has a first holder end **158***a*, and a second holder end **158***b* opposite the first holder end **158***a* along the first direction D.sub.1. The receptacle **154** has a first holder side **158***c* that extends from the first holder end **158***a* to the second holder end **158***b*, as well as a second holder side **158***d* that is opposite the first holder side **158***c* and extends from the first holder end **158***a* to the second holder end **158***b*. The first and second holder sides **158***c* and **158***d* can be considered to be first and second heater plates, although the sides **158***c* and **158***d* can have suitable configurations other than plates, such as coils, for heating the consumable holder **162**. The receptacle **154** can also include a bottom holder end **158***e* that defines the lower end of the receptacle **154** and extends between each of the first and second holder ends **158***a* and **158***b* and between the first and second holder sides **158***c* and **158***d*. The receptacle **154** can define a receiving area **170** configured to receive the consumable holder **162** in order to heat the consumable holder **162**, where the receiving area **170** is defined between each of the first and second holder ends **158***a* and **158***b*, between the first and second holder sides **158***c* and **158***d*, and above the bottom holder end **158***e*. The dimensions and shape of the receiving area **170** can vary depending on the type and shape of consumable holder to be disposed within the receiving area **170**, though in the depicted embodiment the receiving area **170** has a substantially rectangular profile in a plane that extends along the first and second directions D.sub.1 and D.sub.2. The receptacle **154** can be formed from a thermally conductive material such as aluminum, an aluminum alloy, copper, or any other suitable thermally conductive material. A sensor **174** (shown in FIGS. **4** and **6**) can be disposed within the receptacle **154** and can be configured to detect whether a consumable holder **162** has been inserted into the receptacle **154**. The cartridge sensor **174** can be a relay switch or any other suitable sensor that can detect the presence of a consumable holder. The cartridge sensor **174** can be in signal communication with the controller **46** so as to communicate whether a consumable holder **162** has been inserted into the receptacle **154** to the controller **46**.

(41) Turning to FIG. **5**, the biological sample analyzer **10** can support at least a portion of the

receptacle **154** within the air duct **120** of the plenum **100** such that at least one air gap **124** is defined between the receptacle **154** and the at least one plenum wall **104**. This air gap **124**, which comprises a portion of the air duct **120**, allows air to flow along the receptacle **154** in order to cool the receptacle **154**. The air gap **124** can be defined between the at least one plenum wall **104** and any combination of the sides **158***a*-**158***e* of the receptacle **154**. For example, the air gap **124** can include a first air gap **124***a* defined between the first holder side **158***c* of the receptacle **154** and the first plenum sidewall **104***c*. The air gap **124** can additionally or alternatively include a second air gap **124***b* defined between the second holder side **158***d* of the receptacle **154** and the second plenum sidewall **104***d*. The air gap **124** can additionally or alternatively be defined between the bottom holder end **158***e* and the lower plenum wall **104***f*.
(42) Referring to FIG. **6**, to force air through the air duct **120**, the biological sample analyzer **10** can include a fan **192** configured to force air along a path P that extends from the air intake **38** of the housing **14**, through the plenum intake **112** of the plenum **100**, through an air gap **124**, through the plenum exhaust **116**, and out the air exhaust **42** of the housing **14**. Specifically, the fan **192** can direct air through the at least one air gap **124**, such as through at least one of the first air gap **124***a* and the second air gap **124***b* along the first and second lateral sides **158***c* and **158***d* of the receptacle **154**. The fan **192** optionally also direct air through the portion of the air gap **124** defined below the receptacle **154** between the bottom side **158***e* and the plenum wall **104**. In the depicted embodiment, the fan **192** is positioned at the plenum intake **112** of the plenum **100**, although alternative positioning of the fan **192** is contemplated. For example, the fan **192** could alternatively be positioned as the planum exhaust **116**. The fan **192** can be in wired and/or wireless communication with the controller **46**, such that the controller **46** can direct operation of fan **192**. As a result, the fan **192** can be selectively transitioned between different speeds at predetermined intervals in a heating operation, as will be described further below.
(43) Referring back to FIG. **4**, the biological sample analyzer **10** can also include a temperature sensor **194** positioned adjacent the fan **192**, where the temperature sensor **194** is configured to detect the ambient temperature of the air being drawn into the plenum **100** by the fan **192**. The temperature sensor **194** can be in wired and/or wireless communication with the controller **46** such that the controller **46** can monitor the air temperature sensed by the temperature sensor **194**. The temperature of the air forced into the plenum **100** can be representative of the ambient temperature that exists outside the biological sample analyzer **10**, which can be useful in calculations related to the heating operation of the consumable holder **162**, as will be discussed further below. In some embodiments, the analyzer **10** can include another temperature sensor (not shown) on the main printed circuit board (PCB) within the air flow to ensure that air temperature sensed by the sensor **194** is not in skewed due to heat output from the at least one heater of the analyzer.
(44) The biological sample analyzer **10** can also include a filter **196** (see FIG. **4**) positioned upstream from the fan **192**, where the filter **196** is configured to filter out particulates from the air drawn into the plenum **100** by the fan **192**. Over time, the filter **196** can become increasingly clogged, and the filter **196** can become clogged to a sufficient degree that the airflow provided to the fan **192** becomes limited. This reduced airflow can negatively affect the cooling of the receptacle **154**, as less air is available for the fan **192** to force over the receptacle **154**. Obstruction of the filter **196** can be determined by comparing the instantaneous power consumed by the heater **186** to a baseline power consumption. Power consumption by the heater **186** that is lower than expected can be indicative of a clogged filter **196**. The controller **46** can then use this information to adjust the speed of the fan **192**, as will be described further below.
(45) Returning to FIGS. **7** and **8**, the biological sample analyzer **10** can further include at least one heater **186** for heating the receptacle **154**. The at least one heater **186** can apply heat directly or indirectly to the receptacle **154** so as to heat the receptacle **154**. The receptacle **154**, in turn, can apply heat to the consumable holder **162** when the consumable holder **162** is disposed within the receiving area **170** of the receptacle **154**. The at least one heater **186** can be attached to the outer

surface of the receptacle **154**. For example, the at least one heater **186** can be attached to the outer surfaces of any of the first and second holder ends **158***a* and **158***b*, the first and second holder sides **158***c* and **158***d*, and the bottom holder end **158***e*. The at least one heater **186** can comprise an electrically conductive coil supported by a flexible or rigid printed circuit board (PCB), such as a polyimide flexible heater, or any other suitable heater that can heat the receptacle **154**. The at least one heater **186** can include a first heater **186***a* attached to the first holder side **158***c* of the receptacle **154**, and a second heater **186***b*, opposite the first heater **186***a*, and attached to the second holder side **158***d* of the receptacle **154**. However, the heater **186** can include more or less than two heaters as desired. The at least one heater **186**, including the first and second heaters **186***a* and **186***b*, can be in wired and/or wireless signal communication with the controller **46** such that the controller **46** can control and adjust the heating profile of the first and second heaters **186***a* and **186***b* as will be discussed further below.

(46) The biological sample analyzer **10** can include at least one heater sensor **188** configured to detect a temperature of the receptacle **154**. The at least one heater sensor **188** can include first and second heater sensors **188***a* and **188***b* attached to the receptacle **154**, where each of the first and second heater sensors **188***a* and **188***b* can be configured to detect an instantaneous temperature of the receptacle **154** at a different location. The first heater sensor **188***a* can be attached to the first holder side **158***c* of the receptacle **154** adjacent to the first heater **186***a*, and thus, can be configured to detect the temperature of the receptacle **154** at a location adjacent the first heater **186***a*. Likewise, the second heater sensor **188***b* can be attached to the second lateral side **158***d* of the receptacle **154** adjacent the second heater **186***b*, and can thus be configured to detect the temperature of the receptacle **154** at a location adjacent the second heater **186***b*. Each of the first and second heater sensors **188***a* and **188***b* can comprise any suitable temperature sensor such as a thermistor. Though two heater sensors are specifically described, the biological sample analyzer **10** can include more or less than two heater sensors as desired.

(47) The temperature of the biological assay, which is disposed in the consumable holder **162**, cannot be measured directly. Instead, the temperature of the assay can be controlled indirectly based on a temperature of the receptacle **154**. Therefore, the biological sample analyzer **10** can comprise a feedback loop that is configured to control heat applied to the receptacle **154**. The feedback loop can be continuously updated at predetermined intervals (e.g., every second). The feedback loop comprises the controller **46**, the at least one heater **186**, and the at least one heater sensor **188**. The at least one heater sensor **188** can be configured to provide a detected (i.e., measured) temperature of the receptacle **154** to the controller **46**. The controller **46** can be configured to determine a temperature error based on the detected temperature and a desired temperature. The controller **46** can then control an amount of heat provided by the at least one heater **186** based on the temperature error so as to drive the temperature error towards zero error. As will be described below, the desired temperature can be the target temperature, the elevated temperature, or a set point temperature. In one example, the temperature error can be determined as a difference between the desired temperature and the detected temperature. In another example, the temperature error can be determined based on a ratio of the desired temperature and the detected temperature In some such cases, a value of one can be subtracted from the ratio.

(48) Referring to FIGS. **3** and **5**, a biological analysis sensor **190** can be disposed within the housing **14**, where the sensor **190** is configured to measure a characteristic of the biological sample disposed within the consumable holder **162**. In one embodiment, the sensor **190** is an optical sensor, such as a photodiode, though other types of sensors are contemplated. The analyzer **10** can include a light source **191** that is configured to emit a light beam through the consumable holder **162**, and hence through the biological sample, to the sensor **190**. The sensor **190** can be configured to detect at least one of an HbA1C level of the biological sample, a ratio of albumin to creatinine, a hemoglobin level, an agglutination measurement, or any other desired biological characteristic. When the consumable holder **162** is inserted into the receptacle **154**, the biological sample

contained within the consumable holder **162** may require mixing with the reagent prior to the sensor **190** measuring the characteristic of the biological sample. To accomplish this, the biological sample analyzer **10** can include a motor **178** mounted within the housing **14**. The motor **178** can be configured to move the receptacle **154** within the plenum **100** so as to agitate the biological sample within the consumable holder **162**. The motor **178** can include a shaft **182** that extends through the plenum **100** from the motor **178**, and operatively connects to the receptacle **154** opposite the motor **178**. This allows the motor **178** to be disposed within the housing **14** outside the plenum **100**. The motor **178** can be configured to vibrate, rotate, or otherwise agitate the receptacle **154** through the shaft **182**.

(49) The plenum **100** can be specifically designed so as to allow the movement of the receptacle **154** within the plenum **100** so as to mix the biological sample within the consumable holder **162**. For example, the upper portion of the at least one plenum wall **104** can be curved so as to provide a clearance between the plenum **100** and the receptacle **154** and thus allow free movement and/or rotation of the receptacle **154** relative to the plenum **100**. The rest of the plenum wall **104**, including the first and second plenum walls **104***a* and **104***b*, can also be spaced from the receptacle **154** sufficiently to accommodate this movement. This design for the plenum wall **104** can also allow for the plenum **100** to guide air through the air gap **124** along the receptacle **154**. By defining the air gap **124** along each side of the receptacle **154**, the plenum **100** provides a surface area on the receptacle **154** over which air may conduct heat from the receptacle **154**.

(50) Now referring to FIGS. **9** and **12**, a method **200** of operating a biological sample analyzer will be described. The method **200** can begin at step **202**, which corresponds to a startup of the at least one heater **186** of the biological sample analyzer **10**. Upon startup, the controller **46** controls the heater **186** to heat the receptacle **154** to an elevated temperature ET. As shown in FIG. **12**, the receptacle **154** may be at an ambient temperature AT at an initial time t.sub.0. In step **202**, the heater **186** heats the receptacle **154** from the ambient temperature AT at the initial time t.sub.0 to the elevated temperature ET at the first time t.sub.1. In so doing, the controller **46** can determine the elevated temperature ET based on the ambient temperature AT and the target temperature TT. The elevated temperature ET can be stored in the memory **50**, and the controller **46** can look up the elevated temperature ET from predetermined value or values of the elevated temperature ET that are stored in the memory **50** based on the ambient and target temperatures AT and TT. Alternatively, the controller **46** can calculate the elevated temperature ET. The elevated temperature ET for a particular heating operation can be determined according to Equation (1):

(51) $ET = TT + \frac{TT - AT}{SF}$ (1) where: ET=Elevated Temperature TT=Target Temperature AT=Ambient Temperature SF=Initial Slope Factor

(52) In Equation (1), the target temperature TT represents the temperature to which the biological sample within the consumable holder **162** is to be heated for the particular characteristic of the biological sample to be measured. As such, the target temperature TT will vary based on the particular characteristic to be measured. For example, for HbA1c levels, the target temperature TT can be 34° Celsius with a standard deviation of +/−0.4° Celsius when the characteristic to be measured is Hemoglobin. For HbA1c levels, the target temperature TT can be 34° Celsius with a standard deviation of +/−0.2° Celsius when the characteristic to be measured is agglutination. The target temperature TT can be 36° Celsius with a standard deviation of +/−0.4° Celsius when the characteristic to be measured is a ratio of albumin to creatinine. However, other target temperatures are contemplated. The elevated temperature ET may be in a range from greater than TT to about 50° Celsius, though elevated temperatures outside this range are also contemplated. The ambient temperature AT represents the temperature of the ambient environment outside the biological sample analyzer **10** as measured by the temperature sensor **194** adjacent the fan **192**, as previously described. The ambient temperature AT in which the biological sample analyzer **10** can be in a range from about 15° Celsius to about 32° Celsius, though other ambient temperatures are

contemplated. The initial slope factor is a constant that adjusts for the amount of energy needed to apply to the system. If the amount of time that the elevated temperature ET is applied is increased, then the slope factor is increased. The calculations can assume that the consumable holder **162** and heater plates have a fixed mass. Thus, the slope factor can be selected to ensure that the total area under the curve (i.e., the total energy) remains substantially the same from the analysis of one biological sample to the next.

(53) During step **202**, the feedback loop can be employed to raise the receptacle **154** to the elevated temperature ET (from time t.sub.0 to time t.sub.1), and then subsequently maintain the receptacle **154** at the elevated temperature ET (from time t.sub.1 to time t.sub.2). The feedback loop can be continuously updated as described above to control the heat applied by the at least one heater **186** to the receptacle **154**. In this case, the elevated temperature ET is used as the desired temperature to determine the temperature error.

(54) Step **202** can be performed before the consumable holder **162** is inserted into the receptacle **154** to shorten the amount of time required to bring the consumable holder **162** up to the target temperature TT once the consumable holder **162** is disposed within the receptacle **154**. In step **206**, the consumable holder **162** can be inserted into the receptacle **154**. Preferably, the consumable holder **162** is inserted at insertion time t.sub.i between time t.sub.1 and time t.sub.2 as shown in FIG. **12**. The cartridge sensor **174** can detect the insertion of the consumable holder **162** into the receptacle **154** in step **206**, and can communicate to the controller **46** that a consumable holder **162** has been inserted. During steps **202** and **206**, the controller **46** can operate the fan **192** at a first speed as will be discussed further below. The first speed can be zero or can be a relatively low speed, and thus, the fan can be off or can be moving slowly when at the first speed.

(55) In step **210**, the controller **46** can determine whether the door **26** of the housing **14** remains open for a predetermined period. If the door **26** remains open for a certain amount of time after the consumable holder **162** is inserted into the receptacle **154**, then an unknown amount of heat can escape the biological sample analyzer **10** through the opening **22**. As result, the controller may have difficulty in determining how much heat is needed to bring the receptacle **154** to the target temperature TT. In one embodiment, the predetermined period of time can be about 15 seconds, though the period of time can vary. Further, a predetermined period of time can be manually chosen by an operator of the biological sample analyzer by providing an input to the HMI device **54**. If the door **26** is open for more than the predetermined period of time, in step **214** the HMI device **54** can produce an alert to inform the operator that the analysis has faulted. Further, the controller **46** can invalidate the current heating operation. If the door **26** is not open for the predetermined period of time, then the door sensor **30** can continue to monitor whether the door **26** is in the open or closed position throughout the entirety of the method **200**.

(56) When an unheated consumable holder **162** is inserted into the receptacle **154** in step **206**, the lower temperature of the consumable holder **162** in relation to the receptacle **154** (which has been heated to the elevated temperature ET) can cause the temperature of the receptacle **154** to drop measurably. This temperature drop will cause an increase in the temperature error. After insertion, the feedback loop can be continuously updated as described above to heat the receptacle **154** at the elevated temperature ET (from time t.sub.1 to time t.sub.2) and drive the temperature error to zero. In this case, the desired temperature that is used to determine the temperature error is the elevated temperature ET. In at least some embodiments, the at least one heater **186** can increase the heating at a controlled rate that can be repeatable from one consumable holder to the next.

(57) In step **218**, the controller **46** can direct the heater **186** to maintain the receptacle **154** at the elevated temperature ET for a first period of time that extends from the insertion time t.sub.i to a second time t.sub.2 as shown in FIG. **12**. During step **218**, the feedback loop can be continuously updated to maintain the receptacle **154** at the elevated temperature ET (from time t.sub.1 to time t.sub.2). Further, the fan **192** can be operated at the first speed, which is off or relatively low. Maintaining the receptacle **154** at the elevated temperature ET for the first period of time while the

consumable holder **162** is disposed within the receptacle **154** aids in bringing the biological sample disposed within the consumable holder **162** up to the target temperature TT at a quicker rate than in conventional heaters. The first period of time FP can be a predetermined time stored in the memory **50**, and the controller **46** can look up the first period of time FP from predetermined value or values of the first period of time FP that are stored in the memory **50**. Alternatively, the first period of time FP can be entered by the operator into the HMI device **54**. Alternatively still, the controller **46** can calculate the first period of time FP. The first period of time FP can be determined according to Equation (2) as follows:

$$FP=(DTB+AT)*SDM \qquad (2)$$ where: FP=First Period of Time DTB=Decay Time Base AT=Ambient Temperature SDM=Start Decay Multiplier

(58) The decay time base DTB is an offset coefficient that is used to determine the first period of time FP. In some examples, DTB can be about 475. In some embodiments, the first period of time can be fixed when the consumable holder **162** is not determined to be cold as discussed below. The start decay multiplier SDM is a coefficient that is used to reduce the length of time that the consumable holder **162** is heated at the elevated temperature ET. In some embodiments, the Start Decay Multiplier SDM can be about 0.05. This ensures that heating at the elevated temperature ET is stopped before the consumable holder **162** reaches the target temperature. The ambient temperature AT represents the temperature of the environment external to the biological sample analyzer, which is determined by measuring the temperature of air entering the plenum **100** using the temperature sensor **194**. In Equation (2), the first period of time FP is determined based on the ambient temperature AT. Thus, the controller **46** assumes that the consumable holder **162** is at the ambient temperature AT when determining the first period of time FP. However, this might not always be the case as an operator can insert a cold consumable holder into the receptacle **154**. Therefore, the biological sample analyzer **10** can be configured to detect a cold consumable holder as described in further detail below.

(59) In step **222**, the controller **46** can control the biological sample analyzer **10** to perform a temperature decay at the end of the first period of time FP, wherein the temperature of the receptacle **154** is reduced from the elevated temperature ET to the target temperature TT. In particular, the controller **46** can direct the at least one heater **186** to reduce the amount of heat applied to the consumable holder **162** before the consumable holder **162** exceeds the target temperature TT. In addition, the controller **46** can also operate the fan **192** at a second speed, faster than the first speed, to aid in reducing the amount of heat applied to the consumable holder **162**. In one embodiment, the controller **46** can direct the heater **186** to reduce its temperature from the elevated temperature ET to the target temperature TT over a second period of time that extends from the second time t.sub.2 to the third time t.sub.3 as shown in FIG. **12**. As a result, the temperature of the receptacle **154** will decrease from the elevated temperature ET to the target temperature TT. As shown in FIG. **12**, the pattern of temperature decrease from the elevated temperature ET to the target temperature TT can be linear, though other patterns of decreasing the temperature are contemplated. The temperature setpoint of the heater **186** from the second period of time to the third period of time t.sub.3 can be calculated according to Equation (3) below:

(60) $$SP = ISP - \frac{ISP - FSP - ID}{T_{PID} - T_{SD}} \qquad (3)$$ where: SP=Instantaneous Temperature Setpoint ISP=Initial Temperature Setpoint FSP=Final Temperature Setpoint ID=Initial Temperature Drop T.sub.PID=PID Time T.sub.SD=Time to Start Decay

(61) The initial temperature setpoint ISP is the temperature at time t.sub.2 (e.g., the elevated temperature ET). The final temperature setpoint is the temperature at time t.sub.3 (e.g., the target temperature TT). The initial temperature drop ID is an initial drop from the initial temperature setpoint to allow the decay to move quicker. In one example, this value can be set to about a half a degree. The P.sub.ID time is the time as it is kept by the controller **46**. The time to start decay T.sub.SD is the time that the temperature decay starts in step **222**. By reducing the temperature of

the heater **186**, and thus the receptacle **154**, from the elevated temperature ET to the target temperature TT before the consumable holder **162** and the biological sample contained therein are raised to the target temperature TT, the biological sample analyzer **10** can ensure that the temperature of the consumable holder **162** can quickly increase to, but not overshoot, the target temperature TT.

(62) In step **226**, after the temperature of the receptacle **154** is reduced to the target temperature TT and the consumable holder **162** is raised to the target temperature TT, the controller **46** can direct the heater **186** to maintain the receptacle **154** at the target temperature TT. This is shown in FIG. **12** as occurring from the third time t.sub.3 to the fourth time t.sub.4. In addition, the controller **46** can operate the fan **192** at the first speed, or another speed lower than the second speed, so as to limit further cooling of the receptacle **154**. Maintaining the receptacle **154** at the target temperature TT allows the consumable holder **162**, and the biological sample contained therein, to remain at the target temperature TT throughout the process of measuring the characteristic of the biological sample.

(63) In step **230**, the controller **46** directs the motor **178** to actively mix the contents of the consumable holder **162**. In so doing, the motor **178** can rotate the shaft **182** so as to rotate, vibrate, or otherwise move the receptacle **154**, which transfers the motion to the consumable holder **162** contained within the receiving area **170**. Step **230** can be performed concurrently with step **222** (i.e., between the second and third times t.sub.2 and t.sub.3 in FIG. **12**). Alternatively, step **230** can be performed while the heater **186** maintains the receptacle **154** at the target temperature TT (i.e., concurrently with step **226** between the third and fourth times t.sub.3 and t.sub.4 in FIG. **12**), or concurrently with steps **222** and **226**.

(64) Once the biological sample has been sufficiently mixed for a particular measuring operation and enough time has passed for the consumable holder **162** to stabilize at the target temperature, the sensor **190** can measure the characteristic of the biological sample in step **234**. As previously stated, the characteristic can be, for example, an HbA1C level of the biological sample, a ratio of albumin to creatinine in the biological sample, or other suitable characteristic. Once measured, the measured characteristic can be transmitted to the controller **46** from the sensor **190**. Referring to the graph in FIG. **12**, step **234** can be performed after the third time t.sub.3 and before the fourth time t.sub.4, while the receptacle **154** is maintained at the target temperature TT.

(65) Once the characteristic of the biological sample has been measured, an operator can remove the consumable holder **162** from the biological sample analyzer **10** in step **238**. To achieve this, the operator can open the door **26** of the housing **14** and manually remove the consumable holder **162** from the receiving area **170** by grasping the handle **166** connected to the consumable holder **162**. Once the consumable holder **162** has been removed from the receiving area **170**, step **242** can be performed, in which the controller **46** directs the heater **186** to heat the receptacle **154** from the target temperature TT back to the elevated temperature ET. This step is performed so as to preheat the receiving area **170** in preparation for another consumable holder **162** being inserted into the receptacle **154**. As shown in FIG. **12**, step **242** begins at the fourth time t.sub.4, and continues until the fifth time t.sub.5, is which is the time at which the receptacle **154** again reaches the elevated temperature. This allows for a minimal delay between the end of one heating and measuring operation for one consumable holder **162** and the beginning of a subsequent heating and measuring operation for another consumable holder **162**. In one embodiment, this delay can be less than or equal to 20 seconds, though other delays are contemplated.

(66) Referring to FIGS. **9** and **11**, a method of operating the fan **192** will now be described. In step **246**, the controller **46** can direct the fan to operate at a first speed S.sub.1 as the receptacle **154** is brought up to and maintained at the elevated temperature ET (from the from the initial time t.sub.0 to the second time t.sub.2 in FIG. **13**). The first speed can also be referred to as an idle or low speed. In embodiments where the first speed S.sub.1 is greater than zero, the air is forced through the air duct **120** of the plenum **100** and along the receptacle **154** at the first speed S.sub.1.

Operating the fan **192** at a first speed S.sub.1 that is greater than zero can function to transfer excess heat to the air flowing through the plenum **100**, and thus remove at least a portion of the excess heat with the air flowing out of the air exhaust **42** of the housing **14**. This can prevent components in the system from overheating, and can prevent the temperature sensor **194** adjacent the fan **192** that measures the ambient temperature of the air from producing biased measurements as a result of the heat produced by the heater **186**.

(67) While the fan **192** is operated at the first speed S.sub.1, the temperature sensor **194** can sense the ambient temperature AT of the air entering the biological sample analyzer **10** through the air intake **38** in step **250** and transmit the ambient temperature to the controller **46**. The controller **46** can use the ambient temperature AT sensed by the temperature sensor **194** in the calculations described above for determining various temperatures in the heating profile. In step **254**, the controller **46** can direct the fan **192** to increase speed from the first speed S.sub.1 to the second speed S.sub.2 as the heater **186** transitions the receptacle **154** from the elevated temperature ET to the target temperature TT as shown in FIG. **13**. In FIG. **12**, this occurs during the second time t.sub.2. The fan **192** can be operated at the second speed S.sub.2 during the second period of time, which is from the second time t.sub.2 to the third time t.sub.3. The second speed S.sub.2, which is faster than the first speed S.sub.1, can also be referred to as a medium speed. The fan **192** thus forces air through the air duct **120** of the plenum **100** and along the receptacle **154** at the second speed S.sub.2. As the fan **192** is operated at the second speed S.sub.2, heat can be transferred from the receptacle **154** to the air forced through the plenum **100** at a quicker rate than otherwise occurs when the fan **192** is operated at the first speed S.sub.1. This further aids in preventing the consumable holder **162** from overheating past the target temperature TT.

(68) In step **258**, once the receptacle **154** has reached the target temperature TT at the third time t.sub.3 (as shown in FIG. **12**), the controller **46** can direct the fan **192** to reduce speeds from the second speed S.sub.2 to a third speed S.sub.3. The third speed S.sub.3 is less than the second speed S.sub.2. For example, the third speed S.sub.3 can be equal to the first speed S.sub.1, or can be another speed another speed below the second speed S.sub.2, as shown in FIG. **13**. Step **258** can be performed while the heater **186** is maintaining the receptacle **154** at the target temperature TT. Like step **246**, operating the fan **192** at the third speed S.sub.3 in step **258** can function to transfer excess heat to the air flowing through the plenum **100**, and thus remove some of the excess heat with the air flowing out of the air exhaust **42** of the housing **14**.

(69) As described above, the biological sample analyzer **10** can include a filter **196**. If the controller **46** senses that the power consumption of the heater **186** is below expected, the controller **46** can recognize that the filter **196** may be clogged and can subsequently direct the fan **192** to operate during the temperature decay at an elevated speed that is higher than the second speed S.sub.2. Operating the fan **192** at the elevated speed can compensate for the reduced amount of air that is entering the air plenum **100** as a result of the clogged filter **196**, which allows the biological sample analyzer **10** to continue performing heating and sensing operations as normal. As a result, the working life of the filter **196** can be extended. In addition to transitioning the fan **192** to the elevated speed when the filter **196** is clogged, the controller **46** can also produce an alert via the HMI device **54** that indicates to the operator of the biological sample analyzer **10** that the filter **196** is clogged and may require replacement.

(70) Referring to FIGS. **9** and **10**, as described above, in some instances, an operator could insert a cold consumable holder into the biological sample analyzer **10** before allowing the consumable holder to reach ambient temperature. The biological sample analyzer **10** can be configured to detect a cold consumable holder and apply additional heating to the cold consumable holder so as to heat the cold consumable holder to the target temperature for analysis. FIG. **10** shows a method of operating the biological sample analyzer **10** that includes detecting a cold consumable holder and applying additional heating to a detected cold consumable holder so as to heat the cold consumable holder to the target temperature for analysis. The method of FIG. **10** can be implemented as part of

step **206** in FIG. **9**. In general, the sample analyzer **10** can be configured to detect whether the consumable holder is below an ambient temperature based on a decrease in temperature of the receptacle when the consumable holder is inserted into the receptacle. Based on the detection, the analyzer **10** can be configured to 1) control the at least one heater to apply a first amount of thermal energy to the consumable holder when the controller detects that the consumable holder is not below the ambient temperature so as to heat the consumable holder to a target temperature, and 2) control the at least one heater apply a second amount of thermal energy, greater than the first amount of thermal energy, to the consumable holder when the controller detects that the consumable holder is below the ambient temperature so as to heat the consumable holder to the target temperature.

(71) As described above, when an unheated (i.e., cold or ambient temperature) consumable holder **162** is inserted into the receptacle **154**, the lower temperature of the consumable holder **162** in relation to the receptacle **154** (which has been heated to the elevated temperature ET in step **202**) will cause the temperature of the receptacle **154** to drop measurably. This temperature drop will cause an increase in the temperature error (e.g., the difference between the desired temperature and the temperature detected by the at least one heater sensor **188**). The temperature drop for a cold consumable holder will be more rapid than that for an ambient temperature consumable holder. Therefore, the increase in temperature error will be more significant for a cold consumable holder than for an ambient temperature consumable holder. However, insertion of the cold consumable holder may take time (e.g., 5 seconds) to have an effect on the temperature of the receptacle **154** that could be used to identify the consumable holder **162** as a cold consumable holder. Eventually, as the feedback loop returns the receptacle **154** to the elevated temperature ET, the temperature error will be driven back towards zero.

(72) In steps **262-270**, the controller **46** determines whether the consumable holder is below the ambient temperature AT and is thus a cold consumable holder. In particular, in step **262**, each of the at least one heater sensor **188** detects an initial temperature of the receptacle **154** after the consumable holder **162** is inserted into the receptacle **154**. Preferably, this initial temperature is taken after an initial period of time so as to allow effects of the cold consumable holder to be experienced by the receptacle **154**, but before the receptacle **154** returns to the elevated temperature ET. For example, the initial temperature can be measured in seconds after insertion of the consumable holder, such as one second, two seconds, three seconds, four seconds, five seconds, six seconds, seven seconds, eight seconds, nine seconds, or ten seconds after consumable holder insertion. In a preferred embodiment, the initial temperature is taken at five seconds after insertion of the consumable holder. The initial period of time can be based on the thermal time constant of the system, which is the time needed for the at least one heater sensor **188** to respond to a change in temperature. In step **266**, the controller **46** can determine an initial temperature error of the receptacle **154** based on the initial temperature taken in step **262**.

(73) In step **270**, the controller **46** can compare the initial temperature error to a predetermined threshold. If the initial temperature error is within the predetermined threshold (e.g., above or below as appropriate based on how the error is calculated), then the controller **46** can determine that the consumable holder **162** is not a cold consumable holder, and the consumable holder **162** can be heated as described above in relation to the first period of time FP (step **274**). If, on the other hand, the temperature error is outside of the predetermined threshold (e.g., above or below as appropriate based on how the error is calculated), then the controller **46** can determine that the consumable holder **162** is a cold consumable holder and can determine that additional heating is needed to heat the consumable holder **162** to the target temperature (step **278**). In one embodiment, the predetermined threshold can be based on, for example, an expected temperature error, such as (without limitation) a maximum expected temperature, for a non-cold consumable holder at the ambient temperature AT measured by the temperature sensor **194**. If the initial temperature error is outside of a specified range of the expected temperature error (e.g., greater than 20 percent of the

expected temperature error), then the controller **46** can determine that the consumable holder **162** is a cold consumable holder. In such a case, the controller **46** can optionally determine an estimate of an extended first period of time needed to heat the consumable holder **162** to the target temperature based on the initial temperature error. In one example, the estimate of the extended first period of time can be calculated as shown in Equation (4):

(74) $EFP_E = FP\frac{TE_i}{TE_E} + \text{FPc}$ (4) where: EFP.sub.E is an estimate of the extended first period of time; FP is the first period of time discussed above; TE.sub.i is the initial temperature error; TE.sub.E is the expected temperature error; and FP.sub.C is a constant.

(75) In step **276**, the controller **46** can optionally notify the operator that a cold consumable holder is detected. The notification can be provided to the operator via the HMI device **54**, which can produce an alert indicating this condition to the operator. In some embodiments, the controller **46** can provide the estimate of the additional heating time to the operator. The operator may choose to take manual action in response to the relative cold condition of the consumable holder **162**, if desired.

(76) In step **278**, the controller **46** can apply additional heating to the receptacle **154** by increasing the thermal energy transferred to the consumable holder **162**. This increase in thermal energy transfer can aid in driving the temperature error to zero. In one embodiment, the thermal energy transferred can be increased by increasing the power provided to the heater **186**, which can cause the heater **186** to increase its temperature. However, in such embodiments, the at least one heater **186** may require significantly more wattage, which may negatively affect the cost and accuracy of the heating system. In an alternative embodiment, the controller **46** can increase the first period of time during which the receptacle **154** is maintained at the elevated temperature. For example, this increase can be up to about 60 seconds, based upon the extent to which the temperature error is outside the predetermined range.

(77) Therefore, in step **278**, the controller **46** can determine an actual extended first period of time EFP.sub.A to be used to heat the consumable holder **162** to the target temperature. Further, the controller **46** can cause the at least one heater **186** to heat the receptacle **154** to the elevated temperature ET for the actual extended first period of time EFP.sub.A in lieu of the first period of time FP discussed above. The actual extended first period of time EFP.sub.A can be determined based on a summation of a set of the detected temperature errors that are detected by the at least one heater sensor **188** over time for a particular consumable holder **162** so as to provide a more accurate determination than using a single temperature error (as used in the estimated extended first period of time EFP.sub.E above). In one example, the actual extended first period of time can be calculated as shown in Equation (5):

(78) $EFP_A = FP\frac{\Sigma TE_S}{\Sigma TE_E}$ (5) where: EFP.sub.A is the actual extended first period of time; FP is the first period of time discussed above; Σ TE.sub.S is the sum of the detected temperature errors in the set; and Σ TE.sub.E is the sum of the expected temperature errors.

(79) In the Equation (5), the first temperature error in the sum of detected temperature errors Σ TE.sub.S can correspond to about the time that a consumable holder is inserted into the receptacle **154**, although other starting temperature errors can be employed. The last temperature error in the sum Σ TE.sub.S corresponds to a temperature error has not been driven to zero (i.e., before the receptacle **154** reaches the elevated temperature ET). In one embodiment, the last temperature error in the set can correspond to a temperature error that is within a specified percentage of a detected maximum temperature error, although other ending temperature errors can be employed. For example, the specified percentage can be about 75 percent, where the last temperature error in the set would correspond to period where the temperature of the receptacle **154** is increasing and the temperature error is decreasing. The controller **46** can identify the detected maximum temperature error from the temperature errors that are accumulated over time for the particular consumable holder **162**, and determine the last temperature error of the set from the detected maximum

temperature error.
(80) Biological sample analyzers of the present disclosure may provide one or more benefits over conventional analyzers, including one or more of the following benefits. For example, a biological sample analyzer of the present disclosure may be capable of detecting when an inserted consumable holder is a cold consumable holder and adjusting heating of the cold consumable holder to bring the consumable holder of the desired target temperature, whereas a conventional analyzer might not be capable of compensating for a cold consumable holder. This can reduce biases or errors in results of the sample analysis that can occur due to a consumable holder not being properly heated to the target temperature. As another example, a biological sample analyzer of the present disclosure may be capable of heating a consumable holder with a given mass to a target temperature faster than a comparable conventional analyzer. This can result in shorter wait times for measurement results, and shorter wait times between biological analyses of separate consumable holders. As yet another example, a biological sample analyzer of the present disclosure may be capable of cooling its heaters quicker than a comparable conventional analyzer due to the focused air flow over the heaters through the plenum. The focuses air flow can also enable an analyzer of the present disclosure to be operated at a higher temperature than the target temperature so as to more quickly heat a consumable holder.
(81) While various inventive aspects, concepts and features of the inventions may be described and illustrated herein as embodied in combination in the exemplary embodiments, these various aspects, concepts and features may be used in many alternative embodiments, either individually or in various combinations and sub-combinations thereof. Unless expressly excluded herein all such combinations and sub-combinations are intended to be within the scope of the present inventions. Still further, while various alternative embodiments as to the various aspects, concepts, and features of the inventions—such as alternative materials, structures, configurations, methods, circuits, devices and components, software, hardware, control logic, alternatives as to form, fit and function, and so on—may be described herein, such descriptions are not intended to be a complete or exhaustive list of available alternative embodiments, whether presently known or later developed. Those skilled in the art may readily adopt one or more of the inventive aspects, concepts or features into additional embodiments and uses within the scope of the present inventions even if such embodiments are not expressly disclosed herein. Additionally, even though some features, concepts or aspects of the inventions may be described herein as being a preferred arrangement or method, such description is not intended to suggest that such feature is required or necessary unless expressly so stated. Still further, exemplary or representative values and ranges may be included to assist in understanding the present disclosure; however, such values and ranges are not to be construed in a limiting sense and are intended to be critical values or ranges only if so expressly stated. Moreover, while various aspects, features, and concepts may be expressly identified herein as being inventive or forming part of an invention, such identification is not intended to be exclusive, but rather there may be inventive aspects, concepts, and features that are fully described herein without being expressly identified as such or as part of a specific invention, the scope of the inventions instead being set forth in the appended claims or the claims of related or continuing applications. Descriptions of exemplary methods or processes are not limited to inclusion of all steps as being required in all cases, nor is the order that the steps are presented to be construed as required or necessary unless expressly so stated.
(82) While the invention is described herein using a limited number of embodiments, these specific embodiments are not intended to limit the scope of the invention as otherwise described and claimed herein. The precise arrangement of various elements and order of the steps of articles and methods described herein are not to be considered limiting. For instance, although the steps of the methods are described with reference to sequential series of reference signs and progression of the blocks in the figures, the method can be implemented in a particular order as desired.
(83) Unless explicitly stated otherwise, each numerical value and range should be interpreted as

being approximate as if the word “about,” “approximately,” or “substantially” preceded the value or range. The terms “about,” “approximately,” and “substantially” can be understood as describing a range that is within 15 percent of a specified value unless otherwise stated.

Illustrative Embodiments

(84) The foregoing description will be understood with reference to the following illustrative embodiments. It should be understood, however, that the application is not limited to the precise illustrative embodiments discussed below.

(85) Illustrative Embodiment 1: A biological sample analyzer, comprising: a housing having at least one outer wall that defines an internal cavity therein; a receptacle disposed within the internal cavity, the receptacle configured to support a consumable holder containing a biological sample; at least one heater configured to apply heat to the consumable holder when the consumable holder is supported by the receptacle; at least one heater sensor configured to detect a temperature of the receptacle; and a controller configured to 1) direct the at least one heater to heat to an elevated temperature before the consumable holder is disposed in the receptacle, and 2) direct the at least one heater to heat the consumable holder to a target temperature, less than the elevated temperature, by i) applying the elevated temperature to the consumable holder and ii) subsequently reducing an amount of heat applied to the consumable holder before the consumable holder exceeds the target temperature.

(86) Illustrative Embodiment 2: The biological sample analyzer of Illustrative Embodiment 1, wherein the controller is configured to direct the at least one heater to maintain the receptacle at the elevated temperature during a first period of time after the consumable holder is disposed in the receptacle.

(87) Illustrative Embodiment 3: The biological sample analyzer of Illustrative Embodiment 2, wherein the controller is configured to direct the at least one heater to reduce the amount of heat applied to the consumable holder by directing the at least one heater to decrease its temperature from the elevated temperature to the target temperature during a second period of time that is after the first period of time.

(88) Illustrative Embodiment 4: The biological sample analyzer of Illustrative Embodiment 3, comprising a sensor configured to measure a characteristic of the biological sample, wherein the controller is configured to direct the at least one heater to maintain the target temperature while the sensor measures the characteristic of the biological sample.

(89) Illustrative Embodiment 5: The biological sample analyzer of Illustrative Embodiment 4, wherein the controller is configured to direct the at least one heater to heat the receptacle to the elevated temperature after the sensor measures the characteristic of the biological sample and the consumable holder is removed from the receptacle.

(90) Illustrative Embodiment 6: The biological sample analyzer of Illustrative Embodiment 5, wherein the at least one outer wall of the housing defines an air intake and an air exhaust, and the biological sample analyzer comprises a fan configured to force air along a path that extends from the air intake, along the receptacle, and to the air exhaust so as to cool the at least one heater.

(91) Illustrative Embodiment 7: The biological sample analyzer of Illustrative Embodiment 6, comprising a temperature sensor positioned adjacent the fan, wherein the temperature sensor is configured to measure an ambient temperature of the air.

(92) Illustrative Embodiment 8: The biological sample analyzer of any one of Illustrative Embodiments 6 and 7, wherein the controller is configured to operate the fan at a first speed when the at least one heater is at the elevated temperature, and at a second speed, greater than the first speed, as the temperature of the at least one heater is decreasing from the elevated temperature to the target temperature.

(93) Illustrative Embodiment 9: The biological sample analyzer of Illustrative Embodiment 8, wherein the controller is configured to direct the fan to operate at the first speed when the sensor measures the characteristic of the biological sample.

(94) Illustrative Embodiment 10. The biological sample analyzer of any one of Illustrative Embodiments 1 to 9, wherein the at least one heater includes a first heater attached to a first side of the receptacle and a second heater attached to a second side of the receptacle opposite the first side, and the at least one heater sensor includes a first heater sensor attached to the receptacle adjacent the first heater and a second heater sensor attached to the receptacle adjacent the second heater.
(95) Illustrative Embodiment 11: The biological sample analyzer of any one of Illustrative Embodiments 1 to 10, wherein the housing defines a housing opening configured to receive the consumable holder therethrough and into the receptacle, the housing including a door configured to provide access to the receptacle, wherein the door is configured to be moved between an open position, wherein the housing is configured to receive the consumable holder through the opening and into the receptacle, and a closed position, wherein the door covers the housing opening.
(96) Illustrative Embodiment 12: The biological sample analyzer of Illustrative Embodiment 11, comprising a door sensor configured to detect whether the door is open, wherein the controller is configured to produce an alert when the door sensor senses that the door is open for a specified period of time.
(97) Illustrative Embodiment 13: The biological sample analyzer of any one of Illustrative Embodiments 1 to 12, wherein: the controller is configured to determine temperature errors over time, wherein each temperature error is based on a desired temperature and a detected temperature received from the at least one heater sensor; and the controller is configured adjust heat applied by the at least one heater to the receptacle based on the temperature errors so as to heat the receptacle to the desired temperature.
(98) Illustrative Embodiment 14: A method of operating a biological sample analyzer, the method comprising: causing at least one heater to heat a receptacle supported in an internal cavity of a housing of the biological sample analyzer to an elevated temperature; inserting a consumable holder containing a biological sample into the receptacle such that the receptacle applies heat to the consumable holder at the elevated temperature; and causing the at least one heater to reduce an amount of heat applied to the receptacle before the consumable holder exceeds a target temperature, less than the elevated temperature, so as to prevent the consumable holder from exceeding the target temperature.
(99) Illustrative Embodiment 15: The method of Illustrative Embodiment 14, wherein causing the at least one heater to reduce an amount of heat applied to the receptacle comprises causing a fan to force air around the receptacle so as to cool the receptacle.
(100) Illustrative Embodiment 16: The method of any one of Illustrative Embodiments 14 and 15, wherein causing at least one heater supported by the receptacle to heat the receptacle to an elevated temperature comprises adjusting heat applied by the at least one heater to the receptacle based on temperature errors, where each temperature error is determined based on a detected temperature received from at least one heater sensor supported by the receptacle and a desired temperature.
(101) Illustrative Embodiment 17: The method of any one of Illustrative Embodiments 14 to 16, comprising maintaining the receptacle at the elevated temperature for a first period of time after the consumable holder is received in the receptacle.
(102) Illustrative Embodiment 18: The method of Illustrative Embodiment 17, wherein reducing the amount of heat applied to the consumable holder includes decreasing a temperature of the at least one heater from the elevated temperature to the target temperature over a second period of time that is after the first period of time.
(103) Illustrative Embodiment 19: The method of any one of Illustrative Embodiments 14 to 18, comprising causing a sensor to measure a characteristic of the biological sample while maintaining the at least one heater at the target temperature.
(104) Illustrative Embodiment 20: The method of Illustrative Embodiment 19, comprising directing the at least one heater to heat the receptacle to the elevated temperature after the sensor measures

the characteristic of the biological sample and the consumable holder is removed from the receptacle.

Claims

1. A biological sample analyzer, comprising: a housing having at least one outer wall that defines an internal cavity therein; a receptacle disposed within the internal cavity, the receptacle having a receiving area configured to receive therein a consumable holder containing a biological sample; at least one heater attached to the receptacle and configured to apply heat to the receptacle when the consumable holder is not received therein and when the consumable holder is received therein; at least one heater sensor attached to the receptacle and configured to detect a temperature of the receptacle; and a controller in signal communication with the at least one heater and the at least one heater sensor and configured via a software application to 1) direct the at least one heater to heat the receptacle to an elevated temperature before the consumable holder is disposed in the receptacle, and 2) direct the at least one heater to heat the receptacle with the consumable holder disposed therein to a target temperature, which is less than the elevated temperature, by i) applying the elevated temperature to the receptacle with the consumable holder disposed therein and ii) subsequently reducing an amount of heat applied to the receptacle with the consumable holder disposed therein before the consumable holder exceeds the target temperature.
2. The biological sample analyzer of claim 1, wherein the controller is configured to direct the at least one heater to maintain the receptacle at the elevated temperature during a first period of time after the consumable holder is disposed in the receptacle.
3. The biological sample analyzer of claim 2, wherein the controller is configured to direct the at least one heater to reduce the amount of heat applied to the consumable holder by directing the at least one heater to decrease its temperature from the elevated temperature to the target temperature during a second period of time that is after the first period of time.
4. The biological sample analyzer of claim 3, comprising a biological analysis sensor in signal communication with the controller and configured to measure a characteristic of the biological sample, wherein the controller is configured to direct the at least one heater to maintain the target temperature while the biological analysis sensor measures the characteristic of the biological sample.
5. The biological sample analyzer of claim 4, wherein the controller is configured to direct the at least one heater to heat the receptacle to the elevated temperature after the biological analysis sensor measures the characteristic of the biological sample and the consumable holder is removed from the receptacle.
6. The biological sample analyzer of claim 5, wherein the at least one outer wall of the housing defines an air intake and an air exhaust, and the biological sample analyzer further comprises a fan configured to force air along a path in the cavity that extends from the air intake, through a plenum disposed within the cavity along the receptacle, at least a portion of which is received in the plenum, and to the air exhaust so as to cool the at least one heater.
7. The biological sample analyzer of claim 6, comprising a temperature sensor in signal communication with the controller and positioned adjacent the fan, wherein the temperature sensor is configured to measure an ambient temperature of the air drawn into the plenum by the fan.
8. The biological sample analyzer of claim 6, wherein the controller is configured to operate the fan at a first speed when the at least one heater is at the elevated temperature, and at a second speed, greater than the first speed, as the temperature of the at least one heater is decreasing from the elevated temperature to the target temperature.
9. The biological sample analyzer of claim 8, wherein the controller is configured to direct the fan to operate at the first speed when the biological analysis sensor measures the characteristic of the biological sample.

10. The biological sample analyzer of claim 1, wherein the at least one heater includes a first heater attached to a first side of the receptacle and a second heater attached to a second side of the receptacle opposite the first side, and the at least one heater sensor includes a first heater sensor attached to the receptacle adjacent the first heater and a second heater sensor attached to the receptacle adjacent the second heater.
11. The biological sample analyzer of claim 1, wherein the housing defines a housing opening configured to receive the consumable holder therethrough and into the receptacle, the housing including a door configured to provide access to the receptacle, wherein the door is configured to be moved between an open position, wherein the housing is configured to receive the consumable holder through the opening and into the receptacle, and a closed position, wherein the door covers the housing opening.
12. The biological sample analyzer of claim 11, comprising a door sensor in signal communication with the controller and configured to detect whether the door is open, wherein the controller is configured to produce an alert when the door sensor senses that the door is open for a specified period of time.
13. The biological sample analyzer of claim 1, wherein: the controller is configured to determine temperature errors over time, wherein each temperature error is based on a desired temperature and a detected temperature received at the controller from the at least one heater sensor; and the controller is configured to adjust heat applied by the at least one heater to the receptacle based on the temperature errors so as to heat the receptacle to the desired temperature.