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Cepedarizo et al.

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(54) ENERGY HARVESTING SYSTEMS AND METHODS OF ASSEMBLING SAME

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(51) **Int. Cl.**
F02G 3/00 (2006.01)

(52) **U.S. Cl.**
USPC **60/616**; 60/618; 60/620

(58) **Field of Classification Search**
USPC 60/616, 618, 620
See application file for complete search history.

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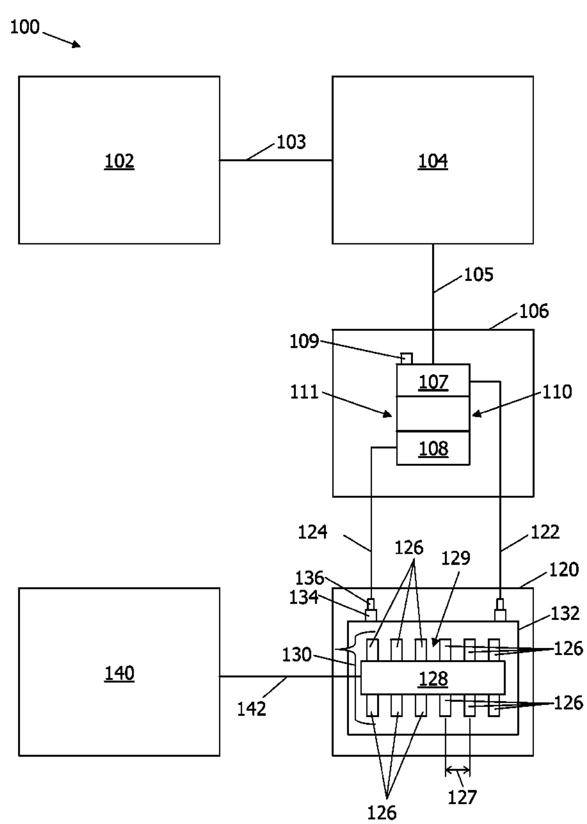
(57) **ABSTRACT**

A method of assembling an energy harvesting system is provided. The method includes coupling at least one energy storage device in flow communication with at least one apparatus that is configured to generate thermal energy and to transfer the thermal energy into at least one fluid stream. The energy storage device is configured to store the fluid stream. Moreover, the method includes coupling at least one fluid transfer device downstream from the energy storage device. The fluid transfer device receives the fluid stream from the energy storage device. A bladeless turbine is coupled in flow communication with the fluid transfer device, wherein the bladeless turbine receives the fluid stream to generate power.

12 Claims, 3 Drawing Sheets



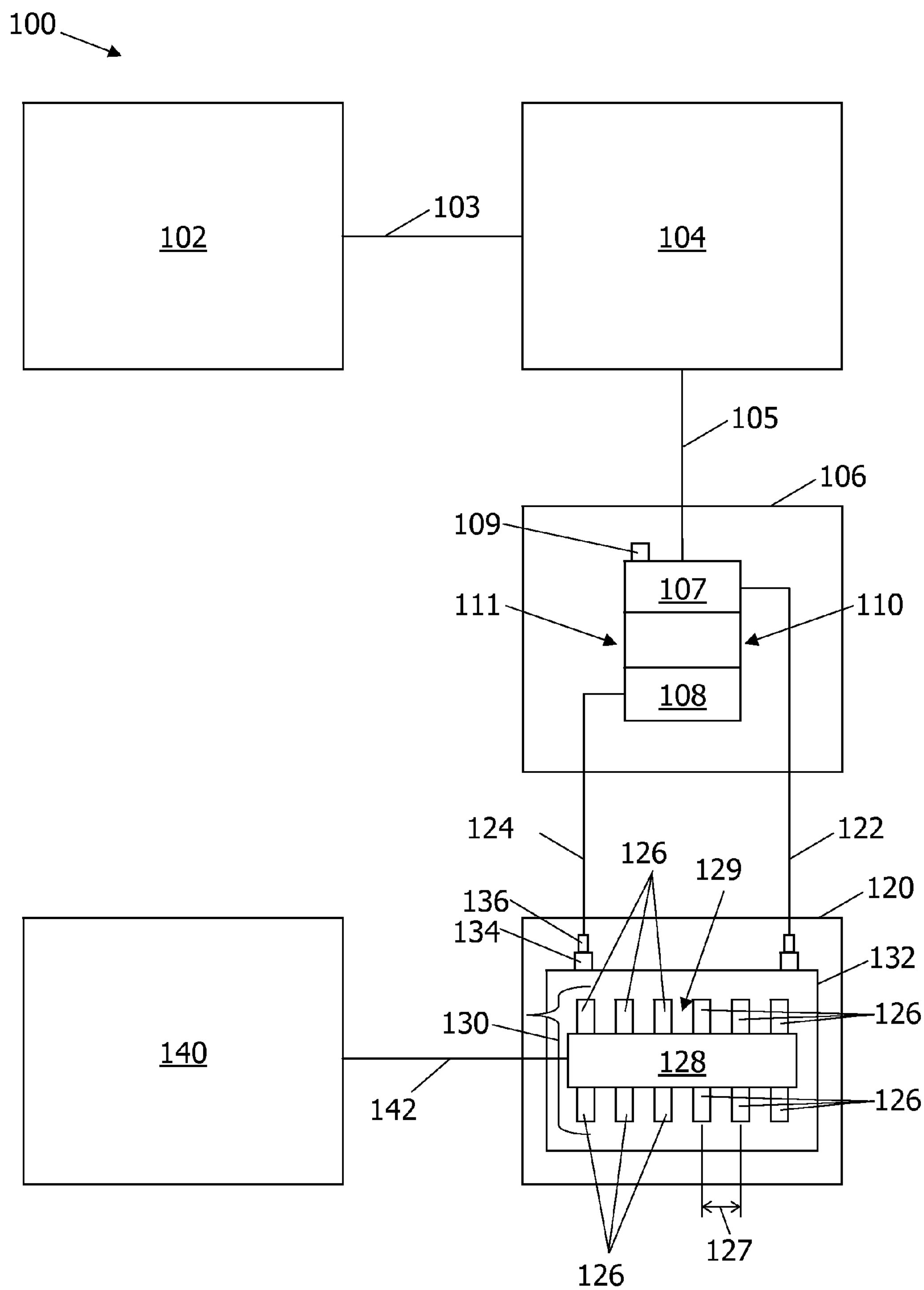

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FIG. 1

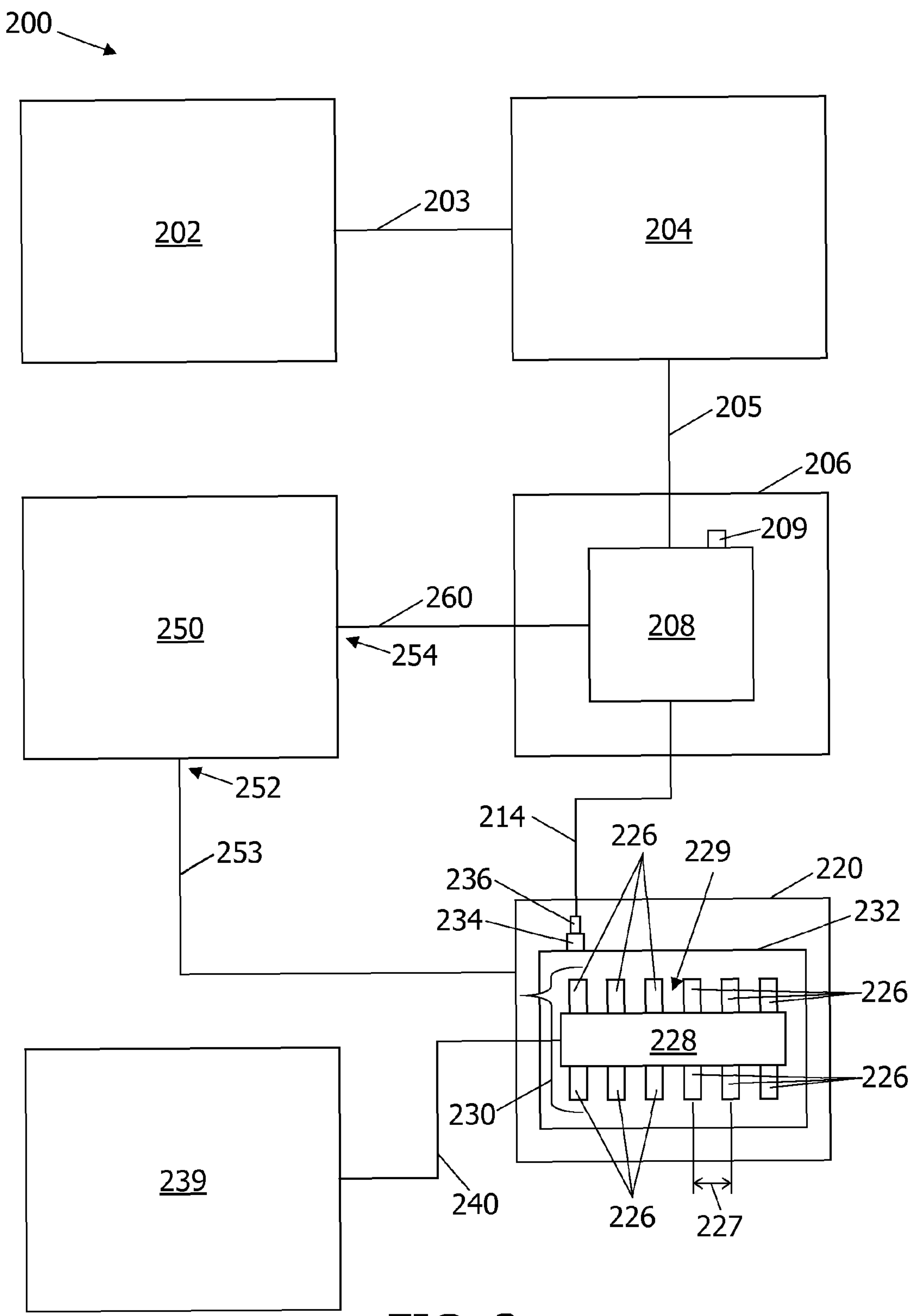
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FIG. 2

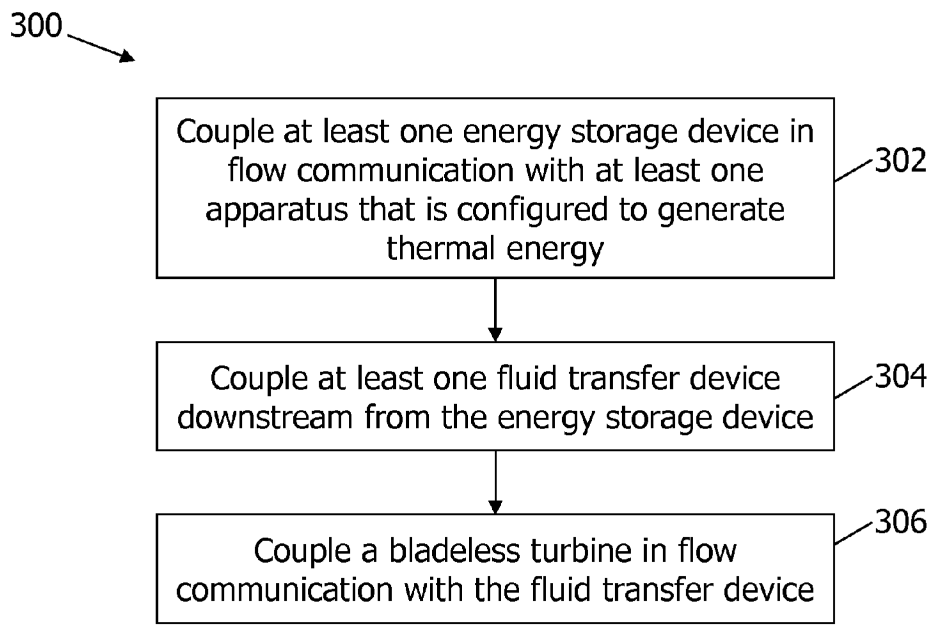
300
Couple at least one energy storage device in flow communication with at least one apparatus that is configured to generate thermal energy
302
Couple at least one fluid transfer device downstream from the energy storage device
304
Couple a bladeless turbine in flow communication with the fluid transfer device
306

FIG. 3

ENERGY HARVESTING SYSTEMS AND METHODS OF ASSEMBLING SAME

STATEMENT OF GOVERNMENT INTEREST

The invention described hereunder was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law #96-517 (35 U.S.C. 202) in which the Contractor has elected not to retain title.

BACKGROUND OF THE INVENTION

The field of the invention relates generally to energy harvesting systems and, more particularly, to energy harvesting systems that convert waste heat to power using a bladeless turbine or a boundary layer turbine.

Waste heat is generated from machines, electrical equipment and industrial processes for which there exists no useful application and is often regarded as a waste by-product. For example, waste heat can be generated from steel mills, concrete plants, smokestacks, and automobile exhausts. Moreover, waste heat can be harvested for power. At least some known systems that harvest waste heat for power use steam turbine engines to convert heat to power by extracting thermal energy from pressurized steam prior to converting the energy into rotary motion used to drive a generator. Known generators convert the mechanical energy into electrical power.

However, the process of converting thermal energy into electrical power via such systems is generally inefficient. Specifically, to generate a large amount of power from thermal energy, a relatively high temperature heat is required. Although, heat losses in such a process contribute greatly to the overall efficiency of the system, the high temperatures are necessary to ensure operation of the system. For example, in at least some known steam turbine engines, the turbines are not operable with liquid flow as liquid may damage the turbine and lead to erosion of the components of the turbine. As such, known energy harvesting systems require additional heating technology, such as superheaters, to ensure any fluid flow is vaporized to steam prior to any flow entering the turbine. Therefore, the cost effectiveness and/or operational efficiency of known energy harvesting systems may be limited.

BRIEF DESCRIPTION OF THE INVENTION

In one embodiment, a method of assembling an energy harvesting system is provided. The method includes coupling at least one energy storage device in flow communication with at least one apparatus that is configured to generate thermal energy and to transfer the thermal energy into at least one fluid stream. The energy storage device is configured to store the fluid stream. Moreover, the method includes coupling at least one fluid transfer device downstream from the energy storage device. The fluid transfer device receives the fluid stream from the energy storage device. A bladeless turbine is coupled in flow communication with the fluid transfer device, wherein the bladeless turbine receives the fluid stream to generate power.

In another embodiment, an energy harvesting system is provided. The energy harvesting system includes at least one apparatus configured to generate thermal energy and to transfer the thermal energy into at least one fluid stream. The energy harvesting system also includes at least one energy storage device that is coupled in flow communication with the apparatus and the energy storage device is configured to store the fluid stream. Moreover, the energy harvesting system includes at least one fluid transfer device that is coupled downstream from the energy storage device for receiving the fluid stream from the energy storage device. Further, the energy harvesting system includes a bladeless turbine that is coupled in flow communication with the fluid transfer device. The bladeless turbine receives the at least one fluid stream to generate power.

In another embodiment, an energy harvesting system is provided. The energy harvesting system includes at least one apparatus configured to generate thermal energy and to transfer the thermal energy into at least one fluid stream. The energy harvesting system also includes at least one energy storage device that is coupled in flow communication with the apparatus and the energy storage device is configured to store the fluid stream. Moreover, the energy harvesting system includes at least one fluid transfer device that is coupled downstream from the energy storage device for receiving the fluid stream from the energy storage device. Further, the energy harvesting system includes a bladeless turbine that is coupled in flow communication with the fluid transfer device and the bladeless turbine receives the at least one fluid stream to generate power. Moreover, the energy harvesting system includes a condensing device that is coupled in flow communication with the bladeless turbine and with the fluid transfer device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an exemplary energy harvesting system;

FIG. **2** is a block diagram of an alternative embodiment of an exemplary energy harvesting system; and

FIG. **3** is an exemplary method of assembling the exemplary energy harvesting systems shown in FIGS. **1** and **2**.

DETAILED DESCRIPTION OF THE INVENTION

The exemplary methods, apparatus, and systems described herein overcome at least some known disadvantages associated with known energy harvesting systems that use waste heat to generate power. In particular, the embodiments described herein provide a system that is efficient and that can convert waste heat to electrical power at a relatively low temperature. The energy systems described herein each use a bladeless turbine or a boundary layer turbine that receives a fluid stream at a relatively low temperature. More specifically, such a turbine operates with using vapor and/or liquid flow, and does not require additional heating technology, such as superheaters.

FIG. **1** illustrates an exemplary energy harvesting system **100**. System **100** includes at least one apparatus **102** that generates thermal energy. For example, in the exemplary embodiment, apparatus **102** is an incinerator. Alternatively, apparatus **102** may be any apparatus or device that is configured to or that is enabled to generate thermal energy, and that enables energy system **100** to function as described herein.

Moreover, in the exemplary embodiment, system **100** also includes at least one energy storage device **104** that is coupled in flow communication with apparatus **102** via a fluid channel **103**. In the exemplary embodiment, energy storage device **104** is a thermal energy storage device **104** that provides a continuous source of heat via a fluid stream.

System **100** includes at least one fluid transfer device **106** that is coupled downstream from the energy storage device **104** via a fluid channel **105**. In the exemplary embodiment, fluid transfer device **106** is a loop heat pipe. Alternatively, fluid transfer device **106** may be any type of device configured to transfer fluid and that enables system **100** to function as described herein. For example, fluid transfer device **106** may be any two-phase heat and/or fluid transfer device that is enabled to use capillary action to passively transfer fluid, such as a capillary pumped loop or a thermosyphon, and that enables system **100** to function as described herein. Moreover, fluid transfer device **106** may be configured to actively transfer fluid via a pump and that enables system **100** to function as described herein.

More specifically, in the exemplary embodiment, the fluid transfer device **106** includes an evaporator **107**, a condenser **108**, and a compensation chamber **109**. Evaporator **107** and condenser **108** are coupled to each other via a fluid channel **110** and a fluid channel **111**. Moreover, evaporator **107** and compensation chamber **109** each contain at least one wick (not shown).

System **100** also includes a bladeless turbine **120** that is coupled in flow communication with fluid transfer device **106**. More specifically, evaporator **107** is coupled to bladeless turbine **120** via a fluid channel **122**, and condenser **108** is coupled to bladeless turbine **120** via a fluid channel **124**.

In the exemplary embodiment, bladeless turbine **120** is a Tesla turbine. Alternatively, bladeless turbine **120** may be any turbine that enables system **100** to function as described herein. More specifically, in the exemplary embodiment, bladeless turbine **120** includes a plurality of disks **126** that are coupled to a rotor shaft **128** to form a rotor **130**. Each disk **126** includes a central opening (not shown) extending therethrough, and shaft **128** extends through each disk opening such that each disk **126** substantially surrounds shaft **128**. Moreover, the disk openings are in flow communication with each other, such that at least one exhaust port (not shown) is defined between disks **126** and shall **128**. Further, each disk **126** is spaced a predetermined distance **127** from each other such that a flow path **129** is defined between adjacent disks **126**.

Bladeless turbine **120** also includes a stationary element **132** at least partially circumscribing rotor **130** such that stationary element **132** and rotor at least partially define a cavity (not shown) between them. Stationary element **132** includes at least one inlet **134**. More specifically, in the exemplary embodiment, stationary element **132** includes two inlets **134**, wherein each inlet **134** is located on opposing ends. Each inlet **134** is coupled to a nozzle **136**, and each nozzle **136** is coupled to fluid channel **122** and fluid channel **124**. Moreover, bladeless turbine **120** is coupled to a generator **140**. More specifically, shaft **128** is coupled to generator **140** via a conduit **142**.

During operation, apparatus **102** generates waste heat, such as thermal energy, and transfers the thermal energy into at least one fluid stream. In the exemplary embodiment, the fluid stream is in a liquid and gaseous state. Energy storage device **104** receives the fluid stream via channel **103** and the fluid stream is stored in device **104**. When power is needed for system **100**, the fluid stream is channeled from energy storage device **104** towards fluid transfer device **106**. More specifically, the fluid stream is channeled via fluid channel **105** to evaporator **107**. As the fluid stream is channeled to evaporator **107**, liquid from the fluid stream is vaporized and a vapor stream is generated from at least a portion of the fluid stream. Moreover, menisci formed in the evaporator wick develop capillary forces that passively channel the vapor stream and/or the remaining fluid stream towards condenser **108** via fluid channel **110**. Alternatively, the vapor stream and/or remaining fluid stream can be channeled directly to turbine **120** via fluid channel **122**.

If the vapor stream and/or the remaining fluid stream is channeled into condenser **108**, condenser **108** generates a liquid stream from the vapor stream and/or the remaining fluid stream channeled therein. The capillary forces passively channel the liquid stream to turbine **120** via fluid channel **124**.

Alternatively, the liquid stream and/or remaining fluid stream may be recirculated back into the evaporator **107**. Specifically, in such an instance, the liquid stream and/or remaining fluid streams are channeled via fluid channel **111** into the evaporator **107**. The compensation chamber **109** stores excess liquid and controls the operating temperature of fluid transfer device **106**.

Bladeless turbine **120** receives the fluid stream from fluid transfer device **106** via either fluid channel **122** or via fluid channel **124**. More specifically, the fluid stream is channeled from fluid channel **122** and/or fluid channel **124** into nozzles **136** at inlets **134**. The fluid stream is then channeled between disks **126** such that flow path **129** is defined between adjacent disks **126**. The fluid stream is then channeled through the exhaust ports defined through the disk openings. The fluid stream channeled between disks **126** induces rotation of disks **126** and shaft **128**. The mechanical energy is then converted into electricity via generator **140** coupled to shaft **128**. Thus, the liquid and/or vapor channeled to turbine **120** creates a rotational force that ultimately produces work from turbine **120**.

In the exemplary embodiment, system **100** is efficient and can convert waste heat to electrical power at a relatively low temperature. More specifically, bladeless turbine **120** receives the fluid stream in either a liquid state and/or gaseous state from fluid transfer device **106**. As such, bladeless turbine **120** operates with using vapor and/or liquid flow, and does not require additional heating technology, such as superheaters. Moreover, bladeless turbine **120** is able to receive the fluid stream at a relatively low temperature. For example, in one embodiment, bladeless turbine **120** receives the fluid stream at a temperature between about 65° C. to about 500 degrees ° C.

FIG. **2** illustrates an alternative embodiment of an exemplary energy harvesting system **200**. In the exemplary embodiment, system **200** includes at least one apparatus **202** that generates thermal energy. For example, in the exemplary embodiment, apparatus **202** is an incinerator. Alternatively, apparatus **202** may be any apparatus or device that is configured or enabled to generate thermal energy, and that enables energy system **200** to function as described herein.

Moreover, in the exemplary embodiment, system **200** also includes at least one energy storage device **204** that is coupled in flow communication with apparatus **202** via a fluid channel **203**. In the exemplary embodiment, energy storage device **204** is a thermal energy storage device **204** that provides a continuous source of heat via a fluid stream.

System **200** includes at least one fluid transfer device **206** that is coupled downstream from the energy storage device **204** via fluid channel **205**. In the exemplary embodiment, fluid transfer device **206** includes an evaporator **208** and a compensation chamber **209**. Energy storage device **204** is coupled to evaporator **208** via fluid channel **205**. Evaporator **208** and compensation chamber **209** each include at least one wick (not shown). Alternatively, fluid transfer device **206** may be any type of device configured to transfer fluid and that enables system **200** to function as described herein. For example, fluid transfer device **206** may be any heat and/or fluid transfer device that is enabled to use capillary action to passively transfer fluid and that enables system **200** to function as described herein. Moreover, fluid transfer device **206** may be configured to actively transfer fluid via a pump (not shown) and that enables system **200** to function as described herein.

System **200** also includes a bladeless turbine **220** that is coupled in flow communication with fluid transfer device **206**. More specifically, evaporator **208** is coupled to bladeless turbine **220** via a fluid channel **214**. In the exemplary embodiment, bladeless turbine **220** is a Tesla turbine. Alternatively, bladeless turbine **220** may be any turbine that enables system **200** to function as described herein.

More specifically, in the exemplary embodiment, bladeless turbine **220** includes a plurality of disks **226** that are coupled to a rotor shaft **228** to form a rotor **230**. Each disk **226** includes a central opening (not shown) extending therethrough, and shaft **228** extends through each disk opening such that each disk **226** substantially surrounds shaft **228**. Moreover, the disk openings are in flow communication with each other, such that at least one exhaust port (not shown) is defined between disks **226** and shaft **228**. Moreover, each disk **226** is spaced a predetermined distance **227** from each other such that a flow path **229** is defined between adjacent disks **226**.

Bladeless turbine **220** also includes a stationary element **232** at least partially circumscribing rotor **230** such that stationary element **232** and rotor **230** at least partially define a cavity (not shown) between them. Stationary element **232** includes at least one inlet **234**. Inlet **234** is coupled to a nozzle **236** and nozzle **236** is coupled to fluid channel **214**. Moreover, bladeless turbine **220** is coupled to a generator **239**. More specifically, shaft **228** is coupled to generator **239** via conduit **240**.

Moreover, system **200** includes a condensing device **250** coupled in flow communication with bladeless turbine **220** and with fluid transfer device **206**. More specifically, a first end **252** of condensing device **250** is coupled in flow communication with turbine **220** via a fluid channel **253** and a second end **254** is coupled in flow communication with fluid transfer device **206** via fluid channel **260**. More specifically, condensing device **250** is coupled to evaporator **208** via channel **260**.

During operation, apparatus **202** generates waste heat, such as thermal energy, and transfers the thermal energy into at least one fluid stream. In the exemplary embodiment, the fluid stream is in a liquid and gaseous state. Energy storage device **204** receives the fluid stream and the fluid stream is stored in device **204**. When power is needed for the system **200**, the fluid stream is channeled from energy storage device **204** towards fluid transfer device **206**. More specifically, the fluid stream is channeled via fluid channel **205** to evaporator **208**. As the fluid stream is channeled to evaporator **208**, liquid from the fluid stream is vaporized and a vapor stream is generated from at least a portion of the fluid stream. Moreover, menisci formed in the evaporator wick develop capillary forces that passively channel the vapor stream and/or the remaining fluid stream towards bladeless turbine **220** via fluid channel **214**.

More specifically, the fluid stream is channeled from fluid channel **214** into nozzle **236** at inlet **234**. The fluid stream is then channeled between disks **226** such that flow path **229** is defined between adjacent disks **226**. Moreover, the fluid stream is channeled through the exhaust ports defined through the openings. The fluid stream channeled between disks **226** induces rotation of disks **226** and shaft **228**. The mechanical energy is then converted into electricity via generator **239** coupled to shaft **228**. Thus; the liquid and/or vapor channeled to bladeless turbine **220** creates a rotational force that ultimately produces work from bladeless turbine **220**.

Any remaining fluid and/or vapor not used by turbine **220** is channeled via fluid channel **253** into condensing device **250**. Condensing device **250** condenses a liquid stream from the vapor and the capillary forces passively channel the liquid stream to fluid transfer device **206** via fluid channel **260**. More specifically, the liquid stream is recirculated to evaporator **208** via channel **260** such that another fluid stream can be channeled to bladeless turbine **220** to generate power.

In the exemplary embodiment, system **200** is efficient and can convert waste heat to electrical power at a relatively low temperature. More specifically, bladeless turbine **220** receives the fluid stream in either a liquid state and/or gaseous state from fluid transfer device **206**. As such, bladeless turbine **220** operates with using vapor and/or liquid flow, and does not require additional heating technology, such as superheaters. Moreover, bladeless turbine **220** is able to receive the fluid stream at a relatively low temperature. For example, in one embodiment, bladeless turbine **220** receives the fluid stream at a temperature between about 65° C. to about 500 degrees ° C. Further, using condensing device **250** after the fluid stream has been channeled through turbine **220** enables system **200** to continue to convert waste heat to electrical power.

FIG. **3** is a flow chart illustrating an exemplary method **300** of assembling an exemplary energy harvesting system, such as energy harvesting system **100** (shown in FIG. **1**) and energy harvesting system **200** (shown in FIG. **2**). In the exemplary embodiment, at least one energy storage device **104** (shown in FIG. **1**) is coupled **302** in flow communication with at least one apparatus **102** (shown in FIG. **1**) that is configured to generate thermal energy and to transfer the thermal energy into at least one fluid stream.

Moreover, at least one fluid transfer device **106** (shown in FIG. **1**) is coupled **304** downstream from energy storage device **104**. Further, a bladeless turbine **120** (shown in FIG. **1**) is coupled **306** in flow communication with fluid transfer device **106**.

The methods and apparatus for an energy harvesting system as described herein facilitates a system that is efficient and that can convert waste heat to electrical power at a relatively low temperature. The energy systems described herein each use a bladeless turbine or a boundary layer turbine that receives a fluid stream at a relatively low temperature. More specifically, such a turbine operates with using vapor and/or liquid flow, and does not require additional heating technology, such as superheaters.

Exemplary embodiments of an energy harvesting system using a bladeless turbine or a boundary layer turbine are described above in detail. The methods, apparatus, and systems are not limited to the specific embodiments described herein nor to the specific illustrated energy harvesting system. While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

Although specific features of various embodiments of the invention may be shown in some drawings and not in others, this is for convenience only. Moreover, references to "one embodiment" in the above description are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. In accordance with the principles of the invention, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A method of assembling an energy harvesting system, said method comprising:

providing an apparatus that generates thermal energy and transfers the thermal energy into at least one fluid stream, the at least one fluid stream being in a both liquid and gaseous states;

coupling at least one fluid transfer device with the apparatus to receive the at least one fluid stream, the fluid transfer device maintaining the at least one fluid stream in both liquid and gaseous states; and

coupling a bladeless turbine in flow communication with the at least one fluid transfer device, wherein the bladeless turbine receives the at least one fluid stream, in both liquid and gaseous states, to generate power.

2. A method in accordance with claim **1** further comprising coupling a condensing device in flow communication with the bladeless turbine and with the at least one fluid transfer device.

3. A method in accordance with claim **1** further comprising configuring the at least one fluid transfer device to passively transfer the at least one fluid stream to the bladeless turbine.

4. A method in accordance with claim **1**, wherein said coupling a bladeless turbine in flow communication with the at least one fluid transfer device further comprises coupling a bladeless turbine in flow communication with the at least one fluid transfer device, wherein the bladeless turbine receives the at least one fluid stream at a temperature between about 65° C. to about 500° C.

5. A method in accordance with claim **1**, wherein said coupling a bladeless turbine in flow communication with the at least one fluid transfer device further comprises coupling a Tesla turbine in flow communication with the at least one fluid transfer device.

6. A method in accordance with claim **1**, wherein said coupling at least one fluid transfer device downstream from the at least one energy storage device further comprises coupling a loop heat pipe with at least one thermal energy storage device.

7. An energy harvesting system comprising:

at least one apparatus configured to generate thermal energy and to transfer the thermal energy into at least one fluid stream, the at least one fluid stream being in both liquid and gaseous states;

at least one fluid transfer device coupled with the at least one apparatus, the fluid transfer device maintaining and transferring the at least one fluid stream in both liquid and gaseous states; and

a bladeless turbine coupled in flow communication with said at least one fluid transfer device, wherein said bladeless turbine receives the at least one fluid stream, in both liquid and gaseous states, to generate power.

8. An energy harvesting system in accordance with claim **7** further comprising a condensing device coupled in flow communication with said bladeless turbine and with said at least one fluid transfer device.

9. An energy harvesting system in accordance with claim **7**, wherein said at least one fluid transfer device is configured to passively transfer the at least one fluid stream to said bladeless turbine.

10. An energy harvesting system in accordance with claim **7**, wherein said at least one fluid transfer device is a loop heat pipe.

11. An energy harvesting system in accordance with claim **7**, wherein said bladeless turbine receives the at least one fluid stream at a temperature between about 65° C. to about 500° C.

12. An energy harvesting system in accordance with claim **7**, wherein said bladeless turbine is a Tesla turbine.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,549,856 B1
APPLICATION NO. : 12/902883
DATED : October 8, 2013
INVENTOR(S) : Cepeda-Rizo et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [75] first inventor's name should read "Juan Cepeda-Rizo" and the second inventor's name should read "Gani B. Ganapathi"

Signed and Sealed this
Twenty-sixth Day of November, 2013

Margaret A. Focarino
Commissioner for Patents of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 8,549,856 B1
APPLICATION NO.	: 12/902883
DATED	: October 8, 2013
INVENTOR(S)	: Cepeda-Rizo et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [12] should read "Cepeda-Rizo et al."

On the title page, item [75] first inventor's name should read "Juan Cepeda-Rizo" and the second inventor's name should read "Gani B. Ganapathi"

This certificate supersedes the Certificate of Correction issued November 26, 2013.

Signed and Sealed this
Fourth Day of February, 2014

Michelle K. Lee

Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office