

1 INTEGRATED FAN DRIVE SYSTEM FOR
2 AIR-COOLED HEAT EXCHANGERS (ACHE)

3
4 CROSS-REFERENCE TO RELATED APPLICATIONS:

5 This application claims the benefit of U.S. provisional application no.
6 61/038,851, filed March 24, 2008. The entire disclosure of the aforesaid application
7 no. 61/038,851 is hereby incorporated by reference.

8
9 TECHNICAL FIELD:

10 The present invention generally relates to fan drive systems for use with air-
11 cooled heat exchangers (ACHE).

12
13 BACKGROUND ART:

14 Air Cooled Heat Exchangers (ACHE) are well known in the art and are used for
15 cooling in a variety of industries including power plants, petroleum refineries,
16 petrochemical and chemical plants, natural gas processing plants, and other industrial
17 facilities that implement energy intensive processes. ACHE exchangers are used
18 typically where there is lack of water, or when water usage permits cannot be
19 obtained, or where there is not sufficient real estate to build a tower. ACHEs lack the
20 cooling effectiveness of "Wet Towers".

21 Typically, an ACHE uses a finned-tube bundle with rectangular box headers on
22 both ends of the tubes. Cooling air is provided by one or more large fans. Usually,
23 the air blows upwards through a horizontal tube bundle. The fans can be either forced
24 or induced draft, depending on whether the air is pushed or pulled through the tube

1 bundle. The space between the fan(s) and the tube bundle is enclosed by a plenum
2 chamber which directs the air (flow field) over the tube bundle assembly thereby
3 providing cooling. The whole assembly is usually mounted on legs or a pipe rack. The
4 fans are usually driven by electric induction motors through some type of speed
5 reducer. The speed reducers are typically V-belts, HTD drives, or right-angle gears.
6 The fan drive assembly is supported by a steel mechanical drive support system.
7 They usually include a vibration switch on each fan to automatically shut down a fan
8 which has become imbalanced for some reason. Airflow is very important in ACHE
9 cooling to ensure that the air has the proper "flow field" and velocity to maximize
10 cooling. Turbulence and "choked-flow conditions can impair cooling efficiency.
11 Therefore, mass airflow is the key parameter to removing heat from the tube and
12 bundle system. ACHE cooling differs from "wet" cooling (i.e. wet cooling towers)
13 towers in that ACHE systems do use water to cool the tube bundle and thus, do not
14 benefit from the latent heat of vaporization or "evaporative cooling".

15 Prior art ACHE fan drive systems use any one of a variety of fan drive
16 components. Examples of such components include electric motors, steam turbines,
17 gas or gasoline engines, or hydraulic motors. The most common drive device is the
18 electric motor. Steam and gas drive systems have been used when electric power is
19 not available. Hydraulic motors have also been used with limited success.
20 Specifically, although hydraulic motors provide variable speed control, they have
21 relatively low efficiencies.

22 Fan-tip speed should not exceed 12,000 feet per minute for mechanical
23 reasons, and may be reduced to obtain lower noise levels. Motor and fan speed are

1 sometimes controlled with variable frequency drives. The most commonly used speed
2 reducer is the high-torque, positive type belt drive, which uses sprockets that mesh
3 with the timing belt cogs. They are used with motors up to 50 or 60 horsepower, and
4 with fans up to about 18 feet in diameter. Banded V-belts are still often used in small
5 to medium sized fans, and gear drives are used with very large motors and fan
6 diameters. Fan speed is set by using a proper combination of sprocket or sheave
7 sizes with timing belts or V-belts, and by selecting a proper reduction ratio with gears.
8 In many instances, right-angle gear boxes are used as part of the fan drive system in
9 order to translate and magnify torque from an offset electrical motor. However, belt
10 drives, pulleys and right-angle gear boxes have poor reliability.

11 The aforesaid complex, prior art mechanical drive systems require stringent
12 maintenance practices to achieve acceptable levels of reliability. In particular, one
13 significant problem with ACHE fan systems is the poor reliability of the belt due to belt
14 tension. A common practice is to upgrade to "timing belts" and add a tension system.
15 One technical paper, entitled "*Application of Reliability Tools to Improve V-Belt Life on*
16 *Fin Fan Cooler Units*", by Rahadian Bayu of PT. Chevron Pacific Indonesia, Riau,
17 Indonesia, presented at the 2007 International Applied Reliability Symposium,
18 addresses the reliability and efficiency of V-belts used in many prior art fan drive
19 systems.

20 The reliability deficiencies of the belt and pulley systems and the gear reducer
21 systems used in the ACHE fan drive systems often result in outages that are
22 detrimental to mission critical industries such as petroleum refining, petro-chemical,
23 power generation and other process intensive industries dependant on cooling.

1 Furthermore, the motor systems used in the ACHE fan drive systems are complex
2 with multiple bearings, auxiliary oil and lubrications systems, complex valve systems
3 for control and operation, and reciprocating parts that must be replaced at regular
4 intervals. Many petroleum refineries, power plants, petrochemical facilities, chemical
5 plants and other industrial facilities utilizing prior art ACHE fan drive systems have
6 reported that poor reliability of belt drive systems and right-angle drive systems has
7 negatively affected production output. These industries have also found that service
8 and maintenance of the belt drive and gearbox system are major expenditures in the
9 life cycle cost, and that the prior art motors have experienced failure due to the mis-
10 use of high pressure water spray.

11 The duty cycle required of an ACHE fan drive system is extreme due to intense
12 humidity, dirt and icing conditions, wind shear forces, corrosive water treatment
13 chemicals, and demanding mechanical drive requirements.

14 In an attempt to increase the efficiency of ACHE cooling systems, some end-
15 users spray water directly on the ACHE system to provide additional cooling on
16 process limiting, hot days. Furthermore, since fan blades can become "fouled" or dirty
17 in regular service and lose performance, many end-users water-wash their ACHE
18 system to maintain their cooling performance. However, directly exposing the ACHE
19 system to high pressure water spray can lead to premature maintenance and/or failure
20 of system components, especially since prior art drive systems are typically open
21 thereby allowing penetration by water and other fluids.

22 Refining of petroleum cannot take place without cooling. Refineries process
23 hydrocarbons at high temperatures and pressures. The loss of cooling within a

1 refinery can lead to unstable and dangerous operating conditions requiring an
2 immediate shut down of processing units. Cooling systems have become "mission
3 critical assets" for petroleum refinery production. As demand for high-end products
4 such as automotive and aviation fuel has risen and refining capacity has shrunk, the
5 refineries have incorporated many new processes that extract hydrogen from the
6 lower value by-products and recombined them into the higher value fuels, improving
7 yield. Many of these processes depend on cooling to optimize the yield and quality of
8 the product. Refining processes also incorporate many advanced processes that
9 need reliable cooling systems to protect profitability. Cooling reliability has become
10 mission critical to refinery profit and is affected by many factors such as environmental
11 limitations on cooling water usage, inelastic supply chain pressures and variable
12 refining margins. Many refineries have been adding processes that reform low grade
13 petroleum products into higher grade and more profitable products such as aviation
14 and automotive gasoline. These processes are highly dependent upon cooling
15 systems to control the process temperatures and pressures that affect the product
16 quality, process yield and safety of the process. In addition, these processes have
17 tapped a great deal of the cooling capacity reserve leaving some refineries "cooling
18 limited" on hot days and even bottlenecked. Most U.S. refineries operate well above
19 90% capacity and thus, uninterrupted refinery operation is critical to refinery profit and
20 paying for the process upgrades implemented over the last decade. The effect of the
21 interruption in the operation of cooling units with respect to the impact of petroleum
22 product prices is described in the report entitled "Refinery Outages: Description and

1 Potential Impact On Petroleum Product Prices", March 2007, U.S. Department of
2 Energy.

3 Thus, the efficiency and production rate of a process is heavily dependent upon
4 the efficiency of the ACHE cooling fan drive system and its ability to remove heat from
5 the system.

6 Therefore, in order to prevent supply interruption of the inelastic supply chain of
7 refined petroleum products, the reliability and subsequent performance of ACHE fan
8 drive systems must be improved and managed as a key asset to refinery production
9 and profit. An efficient and reliable fan drive system is required to maintain a relatively
10 high cooling efficiency and prevent interruptions in production.

11

12 DISCLOSURE OF THE INVENTION:

13 Accordingly, it is an object of the present invention to provide a fan drive
14 system that substantially eliminates the aforementioned problems and disadvantages
15 associated with prior art fan drive systems. The present invention is directed to, in
16 one aspect, a fan drive system for an air-cooled heat exchanger system, comprising a
17 high-torque, low speed permanent magnet motor having a rotatable shaft, a fan
18 comprising a hub that is directly connected to the rotatable shaft and a plurality of fan
19 blades that are attached to the hub, and a variable frequency drive device in electrical
20 signal communication with the permanent magnet motor to control the rotational
21 speed of the permanent magnet motor.

22 In a related aspect, the present invention is directed to an air-cooled heat
23 exchanger system having a forced draft configuration, comprising a structure

1 supporting a tube bundle, a fan rotatably mounted to the structure and positioned
2 under the tube bundle, a high-torque, low speed permanent magnet motor supported
3 by the structure and having a rotatable shaft that is connected to the fan, and a
4 variable frequency drive device in electrical signal communication with the permanent
5 magnet motor to control the rotational speed of the permanent magnet motor.

6 In a further aspect, the present invention is directed to an air-cooled heat
7 exchanger system having an induced draft configuration, comprising a structure
8 supporting a tube bundle, a fan rotatably mounted to the structure and positioned
9 above the tube bundle, a high-torque, low speed permanent magnet motor supported
10 by the structure and having a rotatable shaft that is connected to the fan, and a
11 variable frequency drive device in electrical signal communication with the permanent
12 magnet motor to control the rotational speed of the permanent magnet motor. In one
13 embodiment, the high-torque, permanent magnet motor is positioned above the tube
14 bundle. In another embodiment, the high-torque, permanent magnet motor is
15 positioned below the tube bundle.

16 Other objects of the present invention, as well as particular features, elements
17 and advantages thereof will be apparent from the following description and the
18 accompanying drawing figures.

19

20 BRIEF DESCRIPTION OF THE DRAWINGS:

21 Understanding of the present invention and the various aspects thereof will be
22 facilitated by reference to the accompanying drawing figures submitted for the
23 purposes of illustration only and not intended to define the scope of the invention. In
24 which:

1 FIG. 1 is a basic diagram, partially in cross-section, of an induced draft, air-
2 cooled heat exchanger (ACHE) system that uses a prior art fan drive system;
3 FIG. 2 is a basic diagram, partially in cross-section, of a forced draft, air-cooled
4 heat exchanger (ACHE) system that uses a prior art fan drive system;
5 FIGS. 3 and 4 are side views of a prior art, gear-box type fan drive system;
6 FIG. 5 is a partial, top plan view of a prior art, belt-driven fan drive system;
7 FIG. 6 is a partial, top plan view of a prior art, driven-sprocket fan drive system;
8 FIG. 7 is a partial, side view, in elevation and partially in cross-section, of a
9 forced-draft, ACHE that uses a fan drive system of the present invention;
10 FIG. 8 is a schematic diagram of the fan drive system of the present invention;
11 FIG. 9 is a schematic diagram showing the fan drive system of the present
12 invention in conjunction with a plurality of performance monitoring sensors;
13 FIG. 10 is a plot of motor speed versus horsepower for a high torque, low
14 speed permanent magnet motor used in the fan drive system of the present invention;
15 FIG. 11 is a graph illustrating a comparison in performance between the fan
16 drive system of the present invention and a prior art gearbox-type fan drive system
17 that uses a variable speed induction motor;
18 FIG. 12 is a plot of motor speed versus motor torque for the high torque, low
19 speed permanent magnet motor used in the fan drive system of the present invention;
20 FIG. 13 is a side view, in elevation and partially in cross-section, of an induced
21 draft, ACHE that uses the fan drive system of the present invention; and

FIG. 14 is a side view, in elevation and partially in cross-section, of an induced draft, ACHE that uses the fan drive system of the present invention, the fan drive system being mounted above the tube bundle;

BEST MODE FOR CARRYING OUT THE INVENTION:

Referring to FIG. 1, there is shown a basic diagram of an air-cooled heat exchanger (ACHE) system 10 that uses a prior art fan drive system. ACHE system 10 is configured as an induced draft system. ACHE system 10 generally comprises a support structure that comprises a plurality of support columns 11. Tube bundle 12 is supported by the ACHE support structure. Plenum 13 is located above tube bundle 12. Fan ring 14 is attached to plenum 13. Fan 15 rotates within fan ring 14. Fan 15 has hub 15A. Vertically oriented fan shaft 16 extends through plenum 13 and tube bundle 12 and is connected to prior art fan drive system 17. Fan drive system 17 is typically supported by a support 18 that is connected to support columns 11 and/or other portions of the ACHE support structure. Referring to FIG. 2, there is shown a basic diagram of another air-cooled heat exchanger (ACHE) system 20 that uses a prior art fan drive system. ACHE system 20 is configured as a forced draft system. ACHE system 20 generally comprises a support structure that comprises a plurality of support columns 21. Tube bundle 22 is supported by the ACHE support structure. Plenum 23 is located below tube bundle 22. Fan ring 24 is attached to and positioned under plenum 23. Fan 25 rotates within fan ring 24. Fan 25 has hub 25A. Vertically oriented fan shaft 26 is connected to prior art fan drive system 27. Fan drive system 27 is typically supported by support 28 that is connected to support columns 21 and/or to other portions of the ACHE support structure. Prior art fan drive systems 17 and 27

1 shown in FIGS. 1 and 2, respectively, can be configured as any one of the prior art fan
2 drive systems discussed in the foregoing discussion. FIGS. 3, 4, 5 and 6 show the
3 commonly or widely used prior art fan drive systems. FIGS. 3 and 4 show the
4 common gear-box type fan drive system. This fan drive system, which is generally
5 referred to by reference number 28, comprises induction motor 29 and right-angle
6 gear box 30. The shaft of motor 29 is coupled to right-angle gear box 30 by coupling
7 31. Shaft 32 extends from gear box 30. A coupling 33 is connected to shaft 32.
8 Induction motor 29 and gear box 30 are mounted to support plate 34. Support plate
9 34 is mounted to machinery mount 35. Support plate 34 and machinery mount
10 structure 35 are part of the structure of the ACHE system. Fan mount 36 is attached
11 to coupling 33. The fan (not shown) is connected to fan mount 36. Fan mount
12 support members 37 provide support to fan mount 36.

13 FIG. 5 shows a prior art fan-drive system that uses a belt-drive configuration to
14 drive the fan in an ACHE system. This fan-drive system comprises induction motor 38
15 (shown in phantom), sprocket 39 and belt 40. Sprocket 39 is connected to a fan
16 mount 42. Rotation of the shaft of induction motor 38 causes rotation of sprocket 39
17 which, in turn, causes rotation of the fan (not shown). Induction motor 38 is mounted
18 to a support plate 43 which is adjustably attached to support member 44. Belt-tension
19 adjustment device 45 can adjust the position of support plate 43 with respect to
20 support member 44 in order to adjust the tension on belt 40.

21 FIG. 6 shows a prior art fan-drive system that uses a drive sprocket to drive the
22 fan in an ACHE system. This fan-drive system comprises induction motor 46 (shown
23 in phantom), driver sprocket 47 and driven sprocket 48. Driver sprocket 47 is

1 connected to the shaft 46A of induction motor 46 and engaged with driven sprocket
2 48. Driven sprocket 48 is connected to fan mount 42 which is connected to the fan
3 (not shown). Rotation of driver sprocket 47 causes rotation of driven sprocket 48
4 which, in turn, causes rotation of the fan. Motor 46 is mounted to motor support
5 member 49A. Motor support member 49A is movably attached to support structure
6 49B. Motor position adjustment device 49C can be used to adjust the position of
7 motor support member 49A so as to ensure proper engagement of driver sprocket 47
8 and driven sprocket 48.

9 Referring to FIG. 7, there is shown a partial view of an ACHE system that is
10 configured as a forced draft ACHE and has the same general structural components
11 as the ACHE shown in FIG. 2, except for the prior art fan drive system which has now
12 been replaced with the fan drive system of the present invention. Since this ACHE
13 system is a forced draft system, fan 25 is below tube bundle 22. The fan drive system
14 of the present invention comprises variable frequency drive (VFD) device 50 and
15 motor 52. In accordance with the invention, motor 52 is a high torque, low speed
16 permanent magnet motor. Permanent magnet motor 52 has a high flux density. The
17 superior results, advantages and benefits resulting from permanent magnet motor 52
18 are discussed in the ensuing description. VFD device 50 and permanent magnet
19 motor 52 are mounted to or supported by the support structure 28 of the ACHE
20 system. VFD device 50 is in electrical signal communication with permanent magnet
21 motor 52 via cables or wires 54. Permanent magnet motor 52 has shaft 56 that rotates
22 when the appropriate electrical signals are applied to permanent magnet motor 52.

1 Shaft 56 is connected to fan hub 25A. Thus, rotation of vertical shaft 56 causes
2 rotation of fan 25. Fan 25 rotates within fan ring 23.

3 Referring to FIG. 8, VFD device 50 comprises a variable frequency controller
4 60 and a user or operator interface 62. VFD device 50 controls the speed, direction
5 (i.e. clockwise or counterclockwise), and torque of permanent magnet motor 52. AC
6 input power is inputted into variable frequency controller 60 via input 64. Variable
7 frequency controller 60 converts the AC input power to DC intermediate power.
8 Variable frequency controller 60 then converts the DC power into quasi-sinusoidal AC
9 power that is applied to permanent magnet motor 52. User interface 62 provides a
10 means for an operator to start and stop permanent magnet motor 52 and adjust the
11 operating speed of motor 52. In a preferred embodiment, user interface 62 comprises
12 a microprocessor, and an alphanumeric display and/or indication lights and meters to
13 provide information about the operation of motor 52. User interface 62 further includes
14 a keypad and keypad display that allows the user to input desired motor operating
15 speeds. VFD device 50 includes input and output terminals 70 and 72 for connecting
16 pushbuttons, switches and other operator interface devices or controls signals. In a
17 preferred embodiment, VFD device 50 further includes a serial data communication
18 port 80 to allow VFD device 50 to be configured, adjusted, monitored and controlled
19 using a computer. In one embodiment, VFD device 50 includes sensor signal inputs
20 82, 84, 86, 88 and 89 for receiving sensor output signals. The purpose of these
21 sensors is discussed in the ensuing description.

22 Referring to FIGS. 7 and 8, permanent magnet motor 52 is directly coupled to
23 the fan hub 25A. Since permanent magnet motor 52 is controlled only by electrical

1 signals provided by VFD device 50, there are no couplings, gear boxes, drive shafts or
2 related components as found in the prior art gearbox-type fan drive system shown in
3 FIGS. 3-4, and there are no sprockets, belts and related components as found in the
4 prior art fan drive system shown in FIG. 5, and there are no driver sprockets, driven
5 sprockets and related components as found in the prior art fan drive system shown in
6 FIG. 6. In accordance with the invention, permanent magnet motor 52 is a high-
7 torque, low speed motor. Permanent magnet motor 52 is of simplified design and uses
8 only two bearings 90 and 92 (see FIG. 9). Permanent magnet motor 52 includes stator
9 94. Such a simplified design provides relatively high reliability as well as improved
10 energy efficiency. Permanent magnet motor 52 has relatively low maintenance with a
11 three year lube interval. Permanent magnet motor 52 can be configured with sealed
12 bearings. Permanent magnet motor 52 meets or exceeds the efficiency of Premium
13 Efficiency Induction Motors. Permanent magnet motor 52 substantially reduces the
14 man-hours associated with service and maintenance that would normally be required
15 with a prior art, induction motor fan drive system. In some instances, permanent
16 magnet motor 52 can eliminate up to 1000 man-hours of maintenance and service.
17 Such reliability reduces the amount of cell outages and significantly improves product
18 output.

19 In one embodiment, permanent magnet motor 52 has the following operational
20 and performance characteristics:

21 Speed Range: 0-350 RPM
22 Maximum Power: 75 HP
23 Number of Poles: 12

1 Motor Service Factor: 1:1

2 Rated Current: XX A (rms)

3 Peak Current: 150 A

4 Rated Voltage: 277 V

5 Drive Inputs: 277 V, 3 phase, 60 Hz, 90A (rms max. continuous)

6 FIG. 10 shows a plot of speed vs. horsepower for high torque, low speed
7 permanent magnet motor 52. However, it is to be understood that the aforesaid
8 operational and performance characteristics just pertain to one embodiment of
9 permanent magnet motor 52 and that motor 52 may be modified to provide other
10 operational and performance characteristics that are suited to a particular application.

11 Referring to FIG. 11, there is shown a graph that shows "Efficiency %" versus
12 "Motor Speed (RPM)" for the fan drive system of the present invention and a prior art
13 fan drive system using a variable speed, induction motor. Curve 100 pertains to the
14 present invention and curve 102 pertains to the aforementioned prior art fan drive
15 system. As can be seen in the graph, the efficiency of the present invention is
16 relatively higher than the prior art fan drive system for motor speeds between about
17 125 RPM and about 350 RPM. Referring to FIG. 12, there is shown a plot of motor
18 torque versus motor speed. Permanent magnet motor 52 exhibits substantially
19 constant torque from about 70 RPM to about 425 RPM.

20 Referring to FIG. 9, in a preferred embodiment, the fan drive system of the
21 present invention further comprises a plurality of sensors 200, 202, 204, 206 and 208
22 that provide sensor signals to sensor signal inputs 82, 84, 86, 88 and 89, respectively,
23 of VFD device 50. Sensors 200 and 202 are positioned in proximity to bearings 90

1 and 92, respectively, of permanent magnet motor 52 in order to sense vibration and
2 heat. Sensor 204 is positioned on stator 94 of permanent magnet motor 52 to monitor
3 heat at stator 94. Sensors 206 and 208 are positioned downstream of the air flow
4 created by the fan of the ACHE system to measure airflow. For purposes of
5 simplifying FIG. 9, the fan of the ACHE system is not shown. All sensor output signals
6 applied to sensor signal inputs 82, 84, 86, 88 and 89 are inputted into user interface
7 62 of VFD device 50 and are then routed to an external processing device, such as
8 computer 300, via data port 80. Computer 300 includes a display screen device 302
9 that enables a user or operator to visually monitor the data outputted by sensors 200,
10 202, 204, 206 and 208. Computer 300 further includes a user interface, e.g.
11 keyboard, (not shown) that allows an operator to input commands. Computer 300 is
12 configured to implement a reliability algorithm using the data outputted by sensors
13 200, 202, 204, 206 and 208 and in response, output appropriate control signals that
14 are inputted into user interface 62 via data port 80. Such control signals can be used
15 to adjust the speed of motor 52. Thus, the sensors and computer 300 provide a
16 feedback loop that:

- 17 a) monitors vibrations and heat at the bearings of motor 52;
- 18 b) monitors heat at the stator of motor 52;
- 19 c) monitors airflow produced by the fan of the ACHE system;
- 20 d) provides a trim balance to compensate for fan-unbalance inertia on the
21 cooling tower structure;
- 22 e) alerts the operators to a "blade-out" situation and automatically reduces
23 the speed of motor 52; and

- 1 f) locks out a particular motor speed that creates resonance;
- 2 g) alerts the operator to imbalance such as ice accumulation on fan blades
- 3 and automatically initiates corrective action.
- 4 h) sensor data is used by system logic and software algorithms to provide
- 5 “cooling performance management” of the system. (Cooling performance
- 6 management provides real-time operating, reliability and performance data and
- 7 analysis of the cooling system to predict and schedule corrective action,
- 8 maintenance intervals and provide cooling performance feedback to the
- 9 operator for use in adjusting the process based on cooling performance).

10 Referring to FIG. 13, there is shown an ACHE system that is configured as an
11 induced draft ACHE and has the same general structural components as the ACHE
12 shown in FIG. 1, except for the prior art fan drive system which has now been
13 replaced with the fan drive system of the present invention. In this configuration,
14 variable frequency drive (VFD) device 50 and motor 52 are supported by support
15 member 18. Motor 52 is located below tube bundle 12. Fan 15 is positioned above
16 plenum 13 and rotates within fan ring 14 as described in the foregoing description.
17 One end of vertical shaft 16 is coupled to hub 15A and the other end is coupled to
18 shaft 56 with coupling 150. VFD device 50 is in electrical signal communication with
19 permanent magnet motor 52 via cables or wires 54.

20 Referring to FIG. 14, there is shown another ACHE system that is configured
21 as an induced draft ACHE and which uses the fan drive system of the present
22 invention. ACHE system 200 generally comprises a support structure that comprises
23 a plurality of support columns 202. Tube bundle 204 is supported by the ACHE

1 support structure. Plenum 206 is located above tube bundle 204. Fan ring 208 is
2 attached to plenum 206 and to the support structure of ACHE 200. Fan 210 rotates
3 within fan ring 208. Fan 210 includes hub 212. Plenum 206 has an upper portion to
4 which motor 52 and VFD 50 are mounted. Shaft 56 of motor 52 is directly coupled to
5 hub 212 of fan 210. VFD device 50 is in electrical signal communication with
6 permanent magnet motor 52 via cables or wires 54.

7 Thus, the fan drive system of the present invention provides many advantages
8 and benefits, including:

- 9 a) elimination of many components found in the prior art fan drive systems,
10 such as gear boxes, pulleys, belts, sprockets, drive shafts, couplings,
11 bearings, shaft seals, etc.;
- 12 b) elimination of oil changes;
- 13 c) significant reduction in service and maintenance;
- 14 d) ability to vary the speed of the permanent magnet motor over a relative wide
15 range of speeds;
- 16 e) ability to reverse direction of the permanent magnet motor without any
17 additional components;
- 18 f) consumption of significantly lower amounts of energy in comparison to prior
19 art fan drive systems;
- 20 g) easy retrofit with existing fan thereby eliminating need to construct new
21 ACHE cooling towers or structures;
- 22 h) significant reduction in the occurrence of cell outages; and
23 i) provides significantly more cooling capacity in comparison to prior art

1 gearbox-type fan drive.

2 The operational logic and current system architecture of the present invention
3 will provide the ability to optimize the cooling tower for energy efficiency (e.g. at night
4 when it is cold) and to maximize cooling on hot days or when the process demands
5 additional cooling or to avoid fouling of auxiliary systems such as condenser and heat
6 exchangers.

7 Other significant advantages of the fan drive system of the present invention
8 are improved reliability, in comparison to prior art fan drive systems, "more air flow per
9 ampere" improves electrical efficiency in comparison to prior art systems, and has a
10 relatively smaller footprint due to the elimination the gear train offset thereby providing
11 more space for airflow per envelope and less structural obstructions and passing flow
12 frequency issues. The present invention provides direct-drive simplicity with a simple,
13 two-bearing, robust design. The fan drive system of the present invention is relatively
14 easier to install, maintain and remove. The simple, low-part count design of the fan
15 drive system of the present invention allows it to be "dropped in" existing ACHE
16 installations and eliminates tension-alignment devices that are required by prior art fan
17 drive systems using shafts, belts and pulleys.

18 The permanent magnet motor 52 is capable of providing constant high-torque
19 with infinitely variable speed control that allows an existing installation envelope to be
20 optimized for cooling effectiveness and high energy efficiency. The permanent
21 magnet motor 52 provides high, constant torque and electrical efficiency through-out
22 the entire variable speed range. Thus, with the fan drive system of the present
23 invention, it is easier to match the required mass airflow of a particular application with

1 the high, constant torque and variable speed of permanent magnet motor 52. This is
2 in contrast to the time consuming, iterative approach previously taken to match motor
3 torque to a pulley (i.e. of a prior art fan drive system) to achieve the required torque to
4 rotate the fan while maintaining speed. The prior art fan drive systems using the
5 induction motor and the pulley or gearbox do not have the constant high torque
6 capacity through out the variable speed range of the fan drive system of the present
7 invention. Existing ACHE systems retrofitted with the fan drive system of the present
8 invention realize significant space savings as a result of the elimination of the prior art
9 complex mechanical system. The fan drive system of the present invention is IP 65
10 and/or IP 66 wet environment rated. Furthermore, the fan drive system of the present
11 invention may be integrated with a feedback loop to provide variable cooling load
12 control for cooling performance management.

13 The complex support structure and related "clap trap" of prior art drive systems
14 can result to "passing frequency" and airflow-interruption problems similar to those
15 exhibited in wet cooling towers. However, the direct drive system of the present
16 invention substantially eliminates such problems. .

17 High constant torque of the permanent magnet motor 52, regardless of speed,
18 allows for greater fan pitch and therefore airflow for a given plenum when compared to
19 the incumbent technology and induction motor. Thus, airflow and energy efficiently
20 can be optimized for given demand and outside condition for a given plenum (retrofit)
21 or new application. Thus, the present invention allows for greater design flexibility.

1 In accordance with the invention, permanent magnet motor 52 is a sealed
2 motor unlike prior art motor drive systems which are open to the environment and
3 susceptible to contamination from water, chemicals, dust and foreign particles..

4 Although the foregoing discussion is in terms of the applicability of the present
5 invention to the petroleum industry, it is to be understood that the present invention
6 provides benefits to any industry using ACHE cooling systems. Thus, the present
7 invention has applicability to many industries that consume large amounts of energy
8 and are process intensive, such as the power generation, petro-chemical, pulp and
9 paper, and chemical, glass, mining, steel, and aluminum industries. Other examples
10 of systems, industries and applications to which the present invention may apply
11 include air cooler fans, process coolers /condensers, gas coolers, gas compressor
12 inter/after coolers, steam condensers, seal/lube oil cooler, closed-loop cooling water
13 system coolers, HVAC, geothermal plant condensers, inter-coolers and after-coolers,
14 HVAC and Refrigeration Condensers, Air-Cooled Condensers, Air Cooled Radiators
15 for large stationary power applications such as gensets as well as transportation
16 applications such as rail road locomotives, marine power, mining and large earth
17 moving equipment.

18 It will thus be seen that the objects set forth above, among those elucidated in,
19 or made apparent from, the preceding description, are efficiently attained and, since
20 certain changes may be made in the above construction and/or method without
21 departing from the scope of the invention, it is intended that all matter contained in the
22 above description or shown in the accompanying drawing figures shall be interpreted
23 as illustrative only and not in a limiting sense. It is also to be understood that the

1 following claims are intended to cover all of the generic and specific features of the
2 invention herein described and all statements of the scope of the invention which, as a
3 matter of language, might be said to fall therebetween.
4

WHAT IS CLAIMED IS:

CLAIMS:

1. A fan drive system for an air-cooled heat exchanger system, comprising:

a high-torque, low speed permanent magnet motor having a rotatable shaft;

a fan comprising a hub that is directly coupled to the rotatable shaft and a plurality of fan blades that are attached to the hub; and

a variable frequency drive device in electrical signal communication with the permanent magnet motor to control the rotational speed of the permanent magnet motor.
2. The fan drive system according to claim 2 wherein the high-torque, permanent magnet motor comprises no more than two bearings in operative association with the shaft.

3. The fan drive system according to claim 2 wherein the variable frequency drive device comprises:

a variable frequency controller that has an input for receiving AC power and an output for providing electrical signals that control the operational speed of the high-torque, permanent magnet motor; and

a user interface in electronic data signal communication with the variable frequency controller to allow a user to input data representing a desired motor speed.

4. The fan drive system according to claim 3 further comprising a plurality of sensors in electronic data signal communication with the user interface so as to provide sensor output data signals representing vibration and heat at the bearings of the motor, heat at the motor stator, and air flow created by rotation of the fan.

5. The fan drive system according to claim 4 further comprising a data signal processing resource in electronic data signal communication with the user interface to receive the sensor output data signals.

6. The fan drive system according to claim 5 wherein in response to the sensor output data signals, the data signal processing resource generates feedback signals that are inputted into the user interface to allow adjustment of the motor speed.

7. The fan drive system according to claim 6 wherein the data signal processing resource comprises a computer and a display device.

8. An air-cooled heat exchanger system having a forced draft configuration, comprising:

a structure supporting a tube bundle;

a fan rotatably mounted to the structure and positioned under the tube bundle;

a high-torque, low speed permanent magnet motor supported by the structure and having a rotatable shaft that is connected to the fan; and

a variable frequency drive device in electrical signal communication with the permanent magnet motor to control the rotational speed of the permanent magnet motor.

9. The air-cooled heat exchanger system according to claim 8 wherein the variable frequency drive device comprises:

a variable frequency controller that has an input for receiving AC power and an output for providing electrical signals that control the operational speed of high-torque, permanent magnet motor, and

a user interface in electronic data signal communication with the variable frequency controller to allow a user to input motor speed control data.

10. The air-cooled heat exchanger systems according to claim 8 further comprising a plurality of sensors in electronic data signal communication with the user interface so as to provide sensor data output signals representing vibration and heat at the bearings of the high-torque, permanent magnet motor, heat at the motor stator, and air flow created by operation of the fan.

11. The air-cooled heat exchanger systems according to claim 8 wherein the permanent magnet motor has a rotational speed between 0 RPM and about 350 RPM.

12. An air-cooled heat exchanger system having an induced draft configuration, comprising:

a structure supporting a tube bundle;

a fan rotatably mounted to the structure and positioned above the tube bundle, the fan having a hub to which are attached a plurality of fan blades;

a high-torque, low speed permanent magnet motor supported by the structure and having a rotatable shaft that is connected to the fan; and

a variable frequency drive device in electrical signal communication with the permanent magnet motor to control the rotational speed of the permanent magnet motor.

13. The air-cooled heat exchanger systems according to claim 12 wherein the variable frequency drive device comprises:

a variable frequency controller that has an input for receiving AC power and an output for providing electrical signals that control the operational speed of high-torque, permanent magnet motor, and

a user interface in electronic data signal communication with the variable frequency controller to allow a user to input motor speed control data.

14. The air-cooled heat exchanger systems according to claim 13 further comprising a plurality of sensors in electronic data signal communication with the user interface so as to provide sensor data output signals representing vibration and heat at the bearings of the high-torque, permanent magnet motor, heat at the motor stator, and air flow created by operation of the fan.

15. The air-cooled heat exchanger systems according to claim 12 wherein the high-torque, permanent magnet motor is positioned above the tube bundle.

16. The air-cooled heat exchanger systems according to claim 12 wherein the high-torque, permanent magnet motor is positioned below the tube bundle.

17. The air-cooled heat exchanger systems according to claim 16 further comprising a vertically oriented, elongated shaft connected to and between the hub of the fan and the shaft of the high-torque, permanent magnet motor, the vertically oriented, elongated shaft extending through the tube bundle.

18. The forced draft, air-cooled heat exchanger systems according to claim 12 wherein the permanent magnet motor has a rotational speed between 0 RPM and about 350 RPM.