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NITROGEN BASED THERMAL STORAGE MEDIUM FOR CONCENTRATED SOLAR POWER PLANTS

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ABSTRACT:

The loss of electrical power generation at nighttime in a Concentrated Solar Power Plant (CSP) is circumvented by using thermal storage. Thermal storage material is heated to elevated temperatures during daytime and then stored in large containers. At night, the energy from the heated material is used to generate high pressure steam which drives a turbine generator producing electricity.

Molten salt has been the thermal storage material of choice. Procurement and transportation of large quantities of molten salt to the solar plants at remote locations is a challenge. Molten salt freezes at about 550°F. Expensive additives can lower the freezing temperature. Freezing of molten salt in pipes, valves, heat exchangers and associated components at night leads to a whole new genre of problems. Irregularities in salt composition can alter the melting temperature and thermal properties thereby affecting the thermal storage design.

The patent pending Maarky concept of using nitrogen as the storage medium alleviates a number of disadvantages afflicting the use of molten salt. Eighty percent of Earth's atmosphere is made of nitrogen and available for free. Nitrogen can be easily extracted from the atmosphere at the plant site. Nitrogen has stable thermodynamic properties and can be compressed and stored in large containers. Nitrogen is not combustible and leaks do not cause a safety hazard. If there is a leak then nitrogen escapes to the atmosphere where it came from. Nitrogen remains in gaseous state over a wide range of temperatures. The freezing problem is completely eliminated.

This paper discusses the patent pending Maarky concept of using nitrogen as storage medium in Concentrated Solar Power Plants. The advantages over molten salt systems and the mechanism of usage in various categories of CSPs are discussed.

INTRODUCTION:

The global urgency to reduce carbon dioxide emission and global warming has spurred the attention on alternative sources of energy. Conventional power plants using petroleum based products such as coal, gas and oil are being overlooked in favor of non-polluting alternatives. The design & construction of new nuclear power plants is going through additional scrutiny after the Japanese Fukushima Daiichi nuclear power plant accident in 2011. Solar and wind power have started to be considered as viable alternatives to nuclear, coal and gas fired power generation. Large scale solar and wind generation units are under construction or have been commissioned. Increased investments have energized innovations in the design of wind and solar power plants. Better performing materials at reduced costs have entered the market. Improved designs with inexpensive components have led to power plants with improved performance at lower cost. The trend continues with encouraging results each passing year.

Solar Power Plants, which form a major constituent of the alternative energy portfolio, can be the Photovoltaic type (PV) or the Concentrated Solar Plant type (CSP).

In a Photovoltaic Solar Power Plant electricity is generated by converting solar radiation into electricity using semiconductors that exhibit the Photovoltaic effect. The PV Solar Plants contain a number of solar panels. Each panel includes a number of solar cells containing a photovoltaic material. Advances in material and manufacturing techniques have led to a substantial decrease in the cost of solar panels.

Concentrated Solar Power Plants (CSP) use a large number of mirrors or lenses to concentrate sunlight onto a small area. The heat from the concentrated solar energy is used to directly or indirectly convert high pressure water to steam. The high pressure steam drives a steam turbine-generator unit which produces electricity.

In a Tower type CSP Plant the mirrors focus the sun’s energy to the boiler tubes mounted on top of a tower. Water flows inside the boiler tubes. The concentrated energy from the sun converts water into steam. This is the mechanism for direct heating of water to steam.

In a parabolic mirror CSP Plant, the parabolic mirrors focus the sun’s energy on to a heat transfer fluid (HTF) flowing through a central receiver pipe. The concentrated solar energy heats the HTF. The energy from the HTF is used to convert water to steam in separate large heat exchangers. This is the mechanism for indirect heating of water to steam.

The Concentrated Solar Power Plants operate during daytime. The power plants are essentially shut down at night. The performance of the plant is often affected during cloud cover. Electricity generated from other power plants is required to offset the loss of output from solar power plants at nighttime or during cloud cover.

THERMAL STORAGE:

The loss of electrical power generation at nighttime in a solar power plant is often circumvented using thermal storage. During daytime, part of the captured solar energy is used to heat a thermal storage material to elevated temperatures and then stored in large containers. At night, the energy from the heated thermal storage material is used to directly or indirectly heat high pressure water to high pressure steam. The high pressure steam drives a steam turbine generator producing electricity.

Molten salt has been the thermal storage material of choice. Thermal storage capable of generating electricity for 8-10 hours in the night requires very large quantities of molten salt. Procurement and transportation of molten salt to the plant site located in remote areas is a challenge. Salt is a major component of the fertilizer industry and salt producers are often reluctant to divert years of production quotas to solar power plants. Molten salt freezes at about 550°F. Freezing in pipe lines, valves and associated components at night or cold days results in a whole new genre of problems. Irregularities in the composition of salt alter the melting temperature and thermal properties, thereby affecting the design of the thermal storage in its entirety. To circumvent the freezing problem the entire molten salt containers, heat exchangers and pipelines have to be insulated and/or heat traced. This leads to additional costs and risks.

The disadvantages experienced with molten salt can be eliminated by using pressurized nitrogen as the storage medium. Thermal storage with Nitrogen can be implemented in different ways in the direct heating (Tower Type) and in indirect heating (Parabolic mirror) CSP Plant.

Figure 1 includes a schematic of day and night time operation in a direct heating (Tower Type) CSP Plant. During daytime, the solar field mirrors focus the sun's energy to boiler tubes located on top of a solar tower. In one section of the boiler, pressurized water is converted to steam. The high pressure steam flows through a steam turbine generator assembly producing electricity. The low pressure steam from the steam turbine is condensed in a condenser. The condensate from the condenser is pumped back to the boiler. The above represents a simplified principle of daytime electrical power generation. In a separate section of the boiler tubes, pressurized nitrogen is heated to elevated temperatures and then stored in large containers. During nighttime the energy from heated nitrogen is used to convert high pressure water to steam. The high pressure steam drives a turbine/generator assembly producing electricity at night.

Figure 2 illustrates the schematic of day and night time operation in a direct heating (Tower Type) CSP Plant with a slight variation. Only nitrogen is heated in the boiler tubes located on top of the solar tower. During daytime the solar field mirrors focus the sun's energy to boiler tubes located on top of a solar tower. The sun's energy is used to heat nitrogen to elevated temperatures. Part of the heated nitrogen is used to convert high pressure water to steam in a heat exchanger. The high pressure steam flows through a steam turbine generator assembly producing electricity. The above represents daytime electrical power generation. The remaining high temperature nitrogen from the boiler is stored in large containers. During nighttime the energy from the heated nitrogen is used to convert high pressure water to steam. The high pressure steam drives a turbine/generator assembly producing electricity at night.

Figure 3 illustrates the schematic of day and night time operation in an indirect heating (Parabolic mirror T Type) CSP Plant. The heat transfer fluid (Dowtherm "A" or Terminol etc.) is heated in the central received pipe located in the parabolic mirrors. The energy from a part of the heat transfer fluid (HTF) is used to convert high pressure water to steam in a heat exchanger. The high pressure steam flows through a steam turbine/generator assembly producing electricity. The energy from remaining HTF is used to heat nitrogen to high temperatures. The high temperature nitrogen is stored in large containers. During nighttime, the energy from the stored heated nitrogen is used to convert high pressure water to steam. The high pressure steam drives a turbine/generator assembly producing electricity at night.

Figure 4 illustrates the schematic of day and night time operation in an indirect heating (Parabolic mirror T Type) CSP Plant with a slight variation. The HTF and nitrogen are heated in the central received pipe located in the parabolic mirrors. The energy from heated HTF is used to convert high pressure water to steam in a heat exchanger. The high pressure steam flows through a steam turbine/generator assembly producing electricity. The heated nitrogen from the central receiver pipes is stored in large containers. During nighttime, the energy from the stored heated nitrogen is used to convert high pressure water to steam. The high pressure steam drives a turbine/generator assembly producing electricity at night.

Figure 5 illustrates the schematic of day and night time operation in an indirect heating (Parabolic mirror T Type) CSP Plant with a slight variation. Only nitrogen is heated in the central received pipe in the parabolic mirrors. The energy from part of the heated nitrogen is used to convert high pressure water to steam in a heat exchanger. The high pressure steam flows through a steam turbine/generator assembly producing electricity. The remaining heated nitrogen from the central receiver pipes is stored in large containers. During nighttime, the energy from the stored heated nitrogen is used to convert high pressure water to steam. The high pressure steam drives a turbine/generator assembly producing electricity at night.

The above noted figures illustrate various combinations for deploying the nitrogen thermal storage system in CSP Plants. The magnitude of the nitrogen pressure, number of storage containers and other design aspects of the storage system will depend on the requirements for the CSP Plant, the thermal storage system and the nighttime electrical generation.

CONCLUSION:

Widespread acceptance of Concentrated Solar Power Plants will be dependent on reliable and continuous electrical power generation. The CSP Plant has to generate the required electrical output during daytime, cloud cover and nighttime. The design of thermal storage must be simple, economical, and satisfactorily address problems related to freezing nighttime temperatures. Thermal storage with nitrogen eliminates a number of disadvantages afflicting the present day usage of molten salt storage systems.

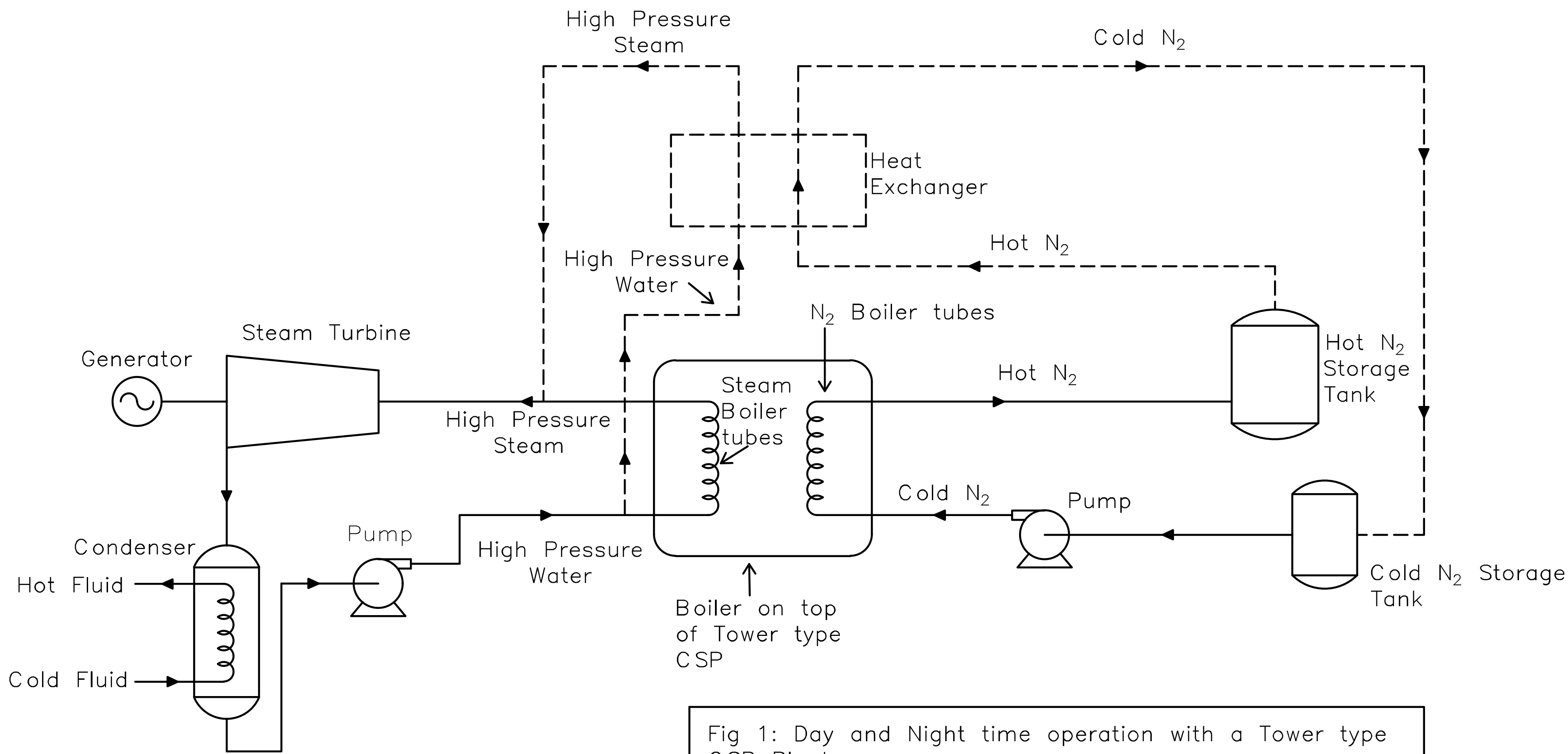

Fig 1: Day and Night time operation with a Tower type CSP Plant.

Solid lines – Day time operation
Dashed lines – Night time operation

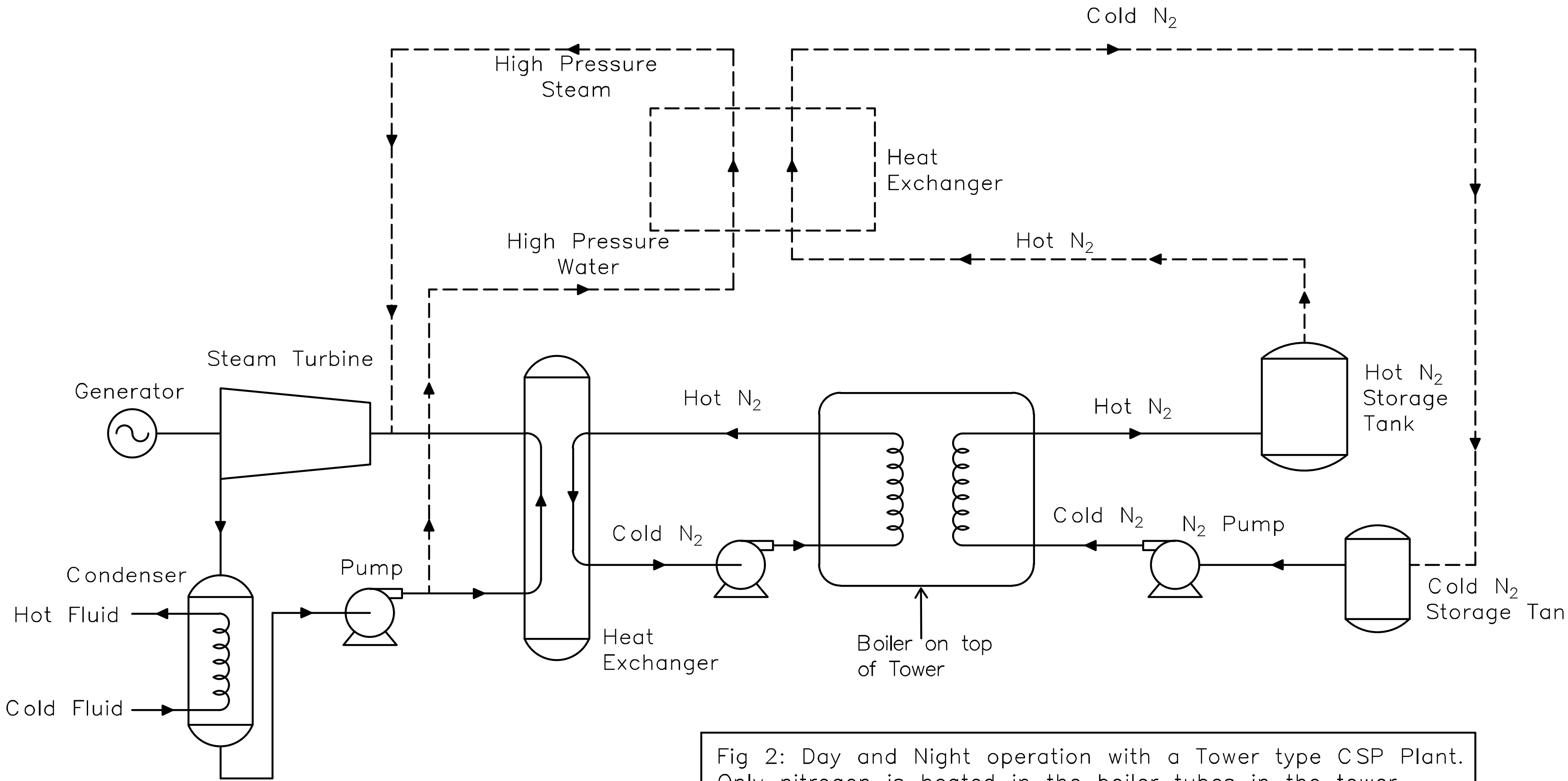

Fig 2: Day and Night operation with a Tower type CSP Plant. Only nitrogen is heated in the boiler tubes in the tower.

Solid lines — Day time operation
Dashed lines — Night time operation

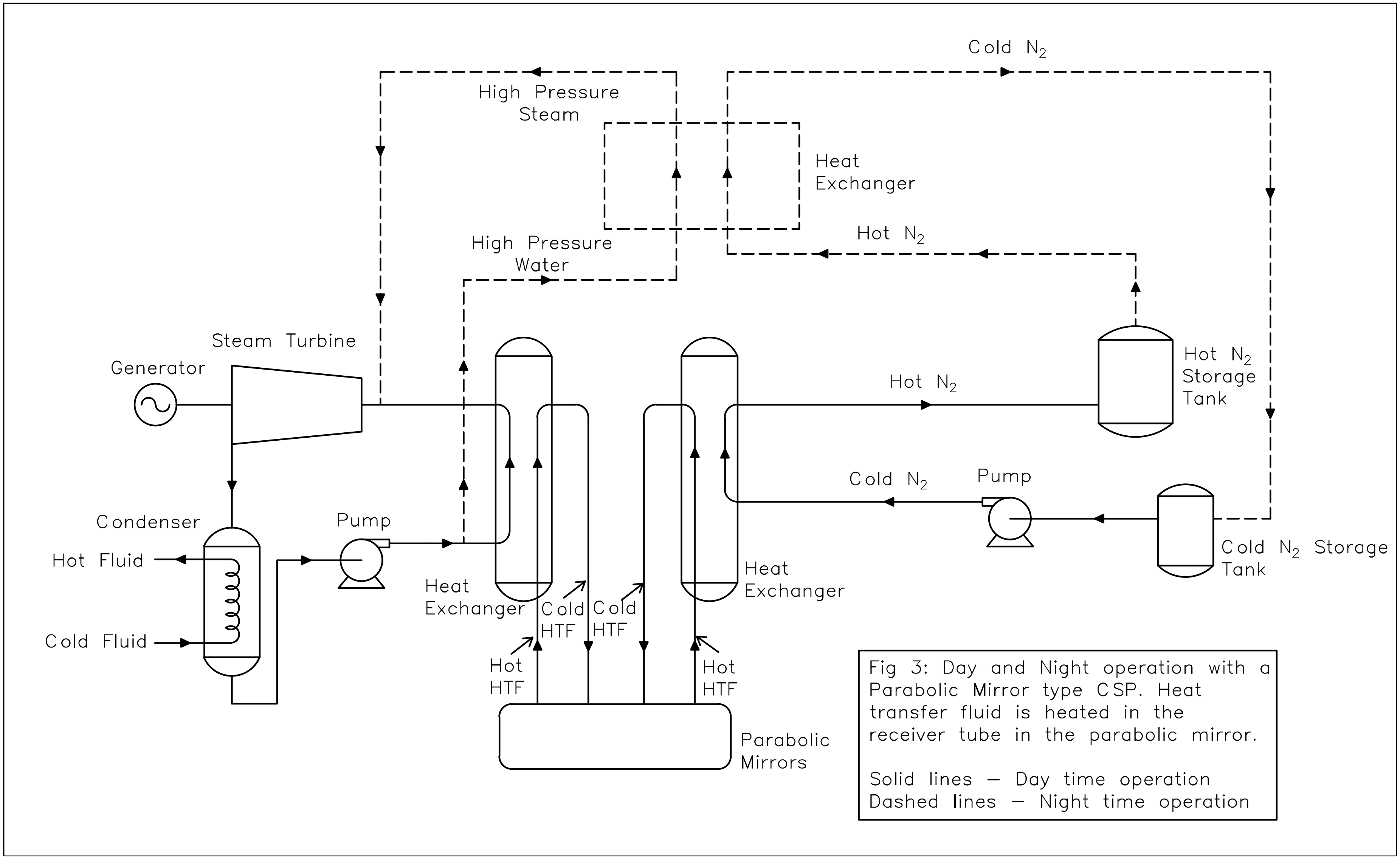

Fig 3: Day and Night operation with a Parabolic Mirror type CSP. Heat transfer fluid is heated in the receiver tube in the parabolic mirror.

Solid lines – Day time operation
Dashed lines – Night time operation

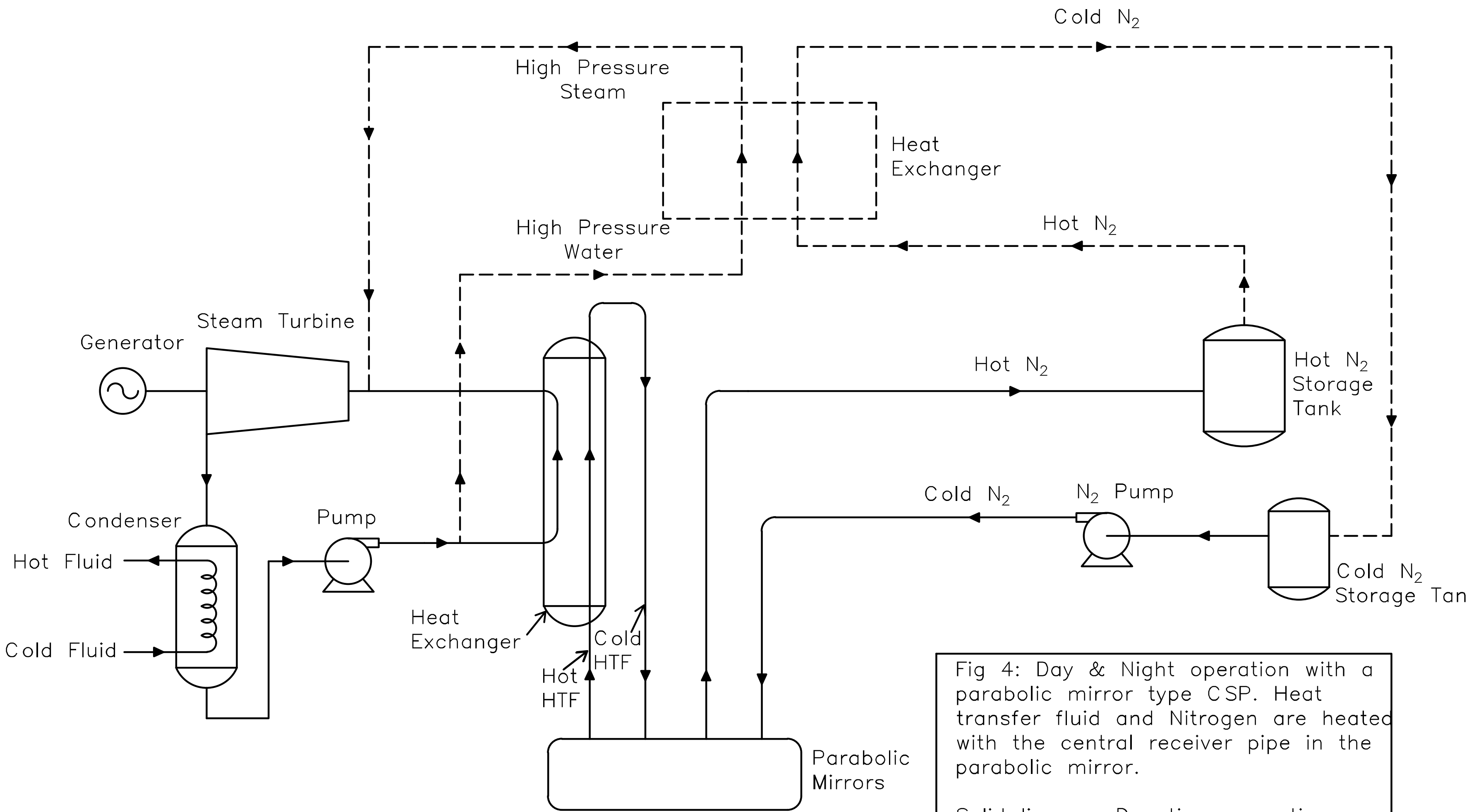

Fig 4: Day & Night operation with a parabolic mirror type CSP. Heat transfer fluid and Nitrogen are heated with the central receiver pipe in the parabolic mirror.

Solid lines – Day time operation
Dashed lines – Night time operation

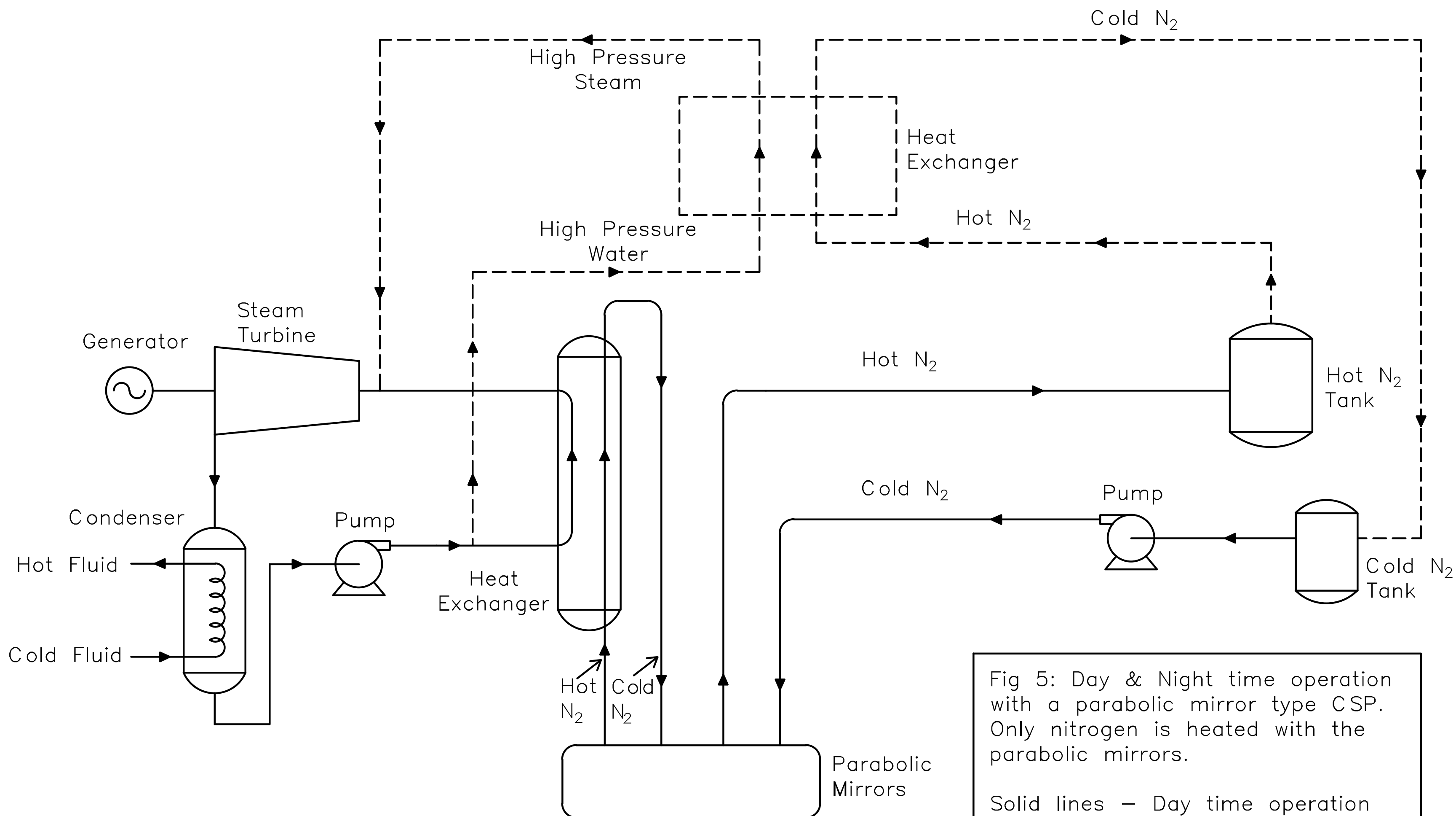

Fig 5: Day & Night time operation with a parabolic mirror type CSP. Only nitrogen is heated with the parabolic mirrors.

Solid lines – Day time operation
Dashed lines – Night time operation