

Researching a GPCS-Accumulator Steam Locomotive

Contributed by Harry Valentine

The hybrid-accumulator steam locomotive idea described in this article is based on input provided by Michael Bahls (Germany) and Robert Ellsworth (USA).

A GPCS-accumulator locomotive would combine the advantages of a fireless steam locomotive with features of a conventional steam locomotive. It would borrow technology from both, combining the high-pressure (1000-psia) accumulator of a fireless locomotive with a GPCS (gas producer combustion system) firebox. Water in the locomotive's accumulator (filled to 75% to 80% capacity) would be heated by injecting pressurised superheated steam into the water through a perforated pipe located near the bottom of the accumulator, a practice pioneered on classical fireless steam locomotives. Water would be heated to the operating temperature and pressure levels (1000-psia at 544-deg F). GPCS-accumulator locomotives would have their water supply replenished and be thermally recharged at industrial sites where high-pressure steam is available and where other types of fireless steam locomotives are recharged.

To maximise power output and operating duration, the locomotive would need to be built to the operating railway's maximum right-of-way clearance dimensions. Several world railway systems allow railcars to be built to a length of 85-ft (between couplers) and a width of 10'6", on 60-ft truck/bogie centres. On such a railway right-of-way, the locomotive accumulator may be built to an inside diameter of 7-ft and interior length of 65-ft (10'6" exterior diameter and 70-ft exterior length), yielding a volume of 2500-cu.ft and holding 90,000-lb of saturated water at 1,000-psia at 80% capacity. The front end of the locomotive could be extended by using a tapered section (containing the driving cab) with the coupler mounted on an extended bogie/truck. The non-tapered end would house the GPCS firebox and be semi-permanently coupled to a fuel tender unit. The locomotive would measure 95-ft to 100-ft from front-end coupler to tender. A driving cab could also be located either on the tender, allowing bi-directional operation.

Prior to the GPCS-accumulator locomotive entering or re-entering service, the accumulator would be filled to 75% volume with hot, pressurised saturated water. It would be further heated with superheated steam to a volume of 80%, a temperature of 544-deg F and 1,000-psia pressure. This would provide one-third of the locomotive's required total thermal energy, which could be supplied from such sources as concentrated solar energy or heat-pumped geothermal energy. While in operation, the locomotive would be able to combust various forms of low cost, clean burning, low heat content (5,000 to 9,000-Btu/lb) biomass, including bio-fuel pellets, poultry litter (eg: Thetford Power Station, UK) or even bagasse carried in a semi-permanently coupled tender unit. Automatic fuel feed (stoking) using an auger screw mechanism would transfer fuel into the GPCS firebox, located on the locomotive section. Combustion ash could be transferred by a smaller auger into a holding pan located under the tender. During service lay-overs, the ash pan would be emptied (biomass ash is a fertilizer).

When the locomotive is in service, steam leaving the accumulator

through the steam dome would be superheated to 1200-deg F in the GPCS firebox, then flow into a heat exchange pipe located inside the accumulator at its lower level. Saturated water at 1,000-psia and 544-deg F has an enthalpy of 542.6-Btu/lb in the liquid state. For this liquid to flash into steam, it would need to draw 650.4-Btu/lb from the remaining saturated liquid. The steam in the steam line would replenish this heat by making 4 to 5 successive passes through the firebox (for re-superheating) and lower level of the accumulator. This heat exchange steam line would allow 650-Btu/lb to be added to the saturated water, maintaining optimal accumulator temperature and pressure levels. The 6th re-superheat would occur prior to the steam being expanded in the steam engine, with a possible 7th re-superheat being used for compound expansion. A variety of positive-displacement single and compound expansion steam engine designs may be located close to the GPCS firebox, directly driving the axles.

The heat exchange steam line inside the accumulator would heat the water in a similar manner as do the firetubes inside a conventional firetube boiler. However, the steam line would be totally immune to any build-up of creosote, clinker or carbon deposits that foul the insides of fire-tubes, greatly reducing locomotive combustion system cleaning and maintenance requirements. The absence of cold water flowing on to a hot and dry crown sheet (of a firetube boiler) is eliminated in a steam-heated accumulator, enhancing "boiler" safety. Baffles would be needed inside the large accumulator to keep the heat exchange steamline covered with water. They would also reduce interior fluid wave action and splashing caused by the locomotive accelerating or decelerating, or by changes in gradient and by lateral swaying (yaw). By using a multi-pass steam line to heat fluid in the accumulator, the (fluidized bed) GPCS firebox and smokebox could be built as a single combined unit. This layout would offer improved energy efficiency while reducing overall combustion system maintenance and cleaning requirements.

The heated accumulator in the locomotive can allow up to 65,000-lb of the saturated water to be used for propulsion, with the remainder covering the heat-exchange steam line. The total energy available for propulsion would be some 40,000-Hp-hr. If the steam engine is an oil-free ceramic unit (from the German company Spilling) capable of receiving steam at over 1200-deg F (enthalpy of 1633-Btu/lb) and operating at a thermal efficiency level of 20%, some 8,000-Hp-hr would be available to the drive wheel. This power level could allow the locomotive to pull a 7-coach double-decker express passenger train at speeds of near 50-miles per hour for up to 5-hrs at 1,500-Hp, operating intercity routes of up to 250-miles. A thermal efficiency level of 25% would allow an operating duration of 6-hours at 1,500-Hp. At the present day, a variety of positive displacement steam engine designs could be built from ceramic materials and operate without oil.

For operation on railways using the UK right-of-way dimensions, overall width would be restricted to 9' 3" by 65-ft length. The accumulator capacity would be reduced to a maximum capacity of 1400-cu.ft (6-ft inside diameter by 50-ft inside length), carry 52,000-lb saturated water at 1,000-psia, of which 39,000-lb could be used for propulsion. On this restricted railway gauge, the driving cab may be located on the tender (train operated with the tender leading), or ahead of the accumulator in a tapered end section of the locomotive. In service, the smaller locomotive operating at 20%-efficiency would be able to provide 1,500-Hp for a 3-hour duration, able to pull light trains along non-electrified lines for distances ranging from 120-miles to

200-miles. If engine efficiency were raised to 25%, the locomotive could deliver 2500-Hp for 2-hours and pull a fast passenger train distances between 140 and 200-miles.

Ted Pritchard of Australia (<http://www.pritchardpower.com>) has designed and built highly efficient Vee-2 compound expansion uniflow piston steam engines that have delivered up to 19% thermal efficiency in mobile operation. This engine design is quite capable of directly driving powered axles through flexible quill-drives, similar to a concept used on the Henschel V-8 steam locomotive. Two designs of rotary uniflow steam engines are also possible, one from the Quasiturbine group of Montreal (Dr. Gilles Saint-Hilaire:<http://quasiturbine.promci.qc.ca>) and one from the Western Railway Group of Boise, Idaho (Tom Blasingame). The latter rotary engine design can operate without mechanical valves, yet offer equivalent minimum inlet valve cut-offs as low as 12.5%, with an equivalent maximum of near 50%. It has very low starting torque and would need to operate in tandem with a piston engine to start the train and enable low-speed operation. If the Quasiturbine was operated as a uni-directional engine, then it does not need any valves ... just inlet and exhaust ports. ... For a steam-powered Quasiturbine to be bi-directional, it may have to use some kind of valve system to direct steam alternatively either at the inlets (forward) or the outlets (reverse direction) ports. Two-Quasiturbines operating at 45-degrees out of phase with each other, would have enough zero-RPM torque to start a train.

A horizontally opposed steam piston engine design that can operate as an underfloor engine, is being designed/evaluated by John Davies and the S-Team in South Africa. In the Ukraine, engineer Viktor Gorondyanskiy has designed a unique multi-piston/ compound-expansion steam engine that can theoretically operate at 35% thermal efficiency, using inlet steam at 1300-deg F (650-deg C). Using a direct mechanical drive system would reduce overall locomotive capital cost (electrical running gear can account for over 60% of locomotive capital cost). Oil-free, self-lubricating jacket heated ceramic steam expanders (engines) would be designed to operate using 250 to 300-psia pressure superheated steam at 1300-deg F. Steam pressure would be reduced from 1,000-psia accumulator pressure entering the steam line, to 297-psia using 2-expansion valves, each causing a pressure drop of 54.5% ($1000\text{-psia} \times 0.545 \times 0.545 = 297\text{-psia}$). Since steam engines give their highest energy efficiency levels when operating at part load and at minimal inlet valve cut-off ratios, large overall engine displacements would be optimal.

The operating range and power level could be extended, by re-using a portion of the exhaust steam. The Swedish Ranotor company (<http://www.ranotor.se>) designs and builds heat exchangers that can condense the steam, however, effective condensing only works on lower-powered steam locomotives. The maximum possible size of the heat-exchangers that can be fitted to a railway vehicle, restricts how much thermal energy can be managed and in turn imposes power restrictions on locomotive output. Prior to being pumped at high-pressure into the accumulator, the water would pass through several (4 to 6) coiled monotube boilers that would heat the 1,000-psia water to 540-deg F, adding 3,000,000 to 4,500,000-Btu/hr (5500 to 8200-lb/hr) to the accumulator. This could add up to 1-hour of extra operating duration and operating range to the locomotive.

The GPCS-accumulator locomotive may be operated on intercity journeys up to 250-miles, along non-electrified routes. It is an alternative form of rail traction intended for operation during an era where oil becomes scarce and oil prices escalate to levels that make alternative fuels economically more viable. Most of the componentry to build a GPCS-accumulator locomotive already exists.

Harry Valentine,

Transportation Researcher.

harrycv at hotmail.com

<http://www.internationalsteam.co.uk/trains/newsteam/modern31.htm>