**Review of implementation of PSA oxygen generating plants**

March 2024

**Objectives:**

The objective is to monitor and verify end-to-end implementation of PSA (pressure swing absorption) oxygen generating plants and to identify circumstances and risks that may impact the success of a new PSA plant.

**Scope of Review *[detailed scope to be agreed with the Country Team prior to commencing the review]*:**

1. Desk review: Review of available documentation including but not limited to budget, procurement documents, PSA plant specifications, maintenance, and warranty, allocated human resources, currently available technical assistance) pertaining to the implementation of one or more PSA plants funded by the Global Fund.
2. Site visits: Visit to hospital requesting a new PSA plant or where there is an existing PSA plant, discussion with key hospital staff responsible for oxygen supply and delivery and walkthrough of hospital campus to observe potential environmental and geographic constraints.

**Tasks:**

*As part of the desk review and visit to the site, answer the following questions to verify PSA plant characteristics, site suitability and implementation plan.*

1. **Hospital Information**

|  |  |
| --- | --- |
| Question | Response |
| 1. Hospital name:
 |  |
| 1. Location (city, address, coordinates):
 |  |
| 1. Names and contact information of key informants and staff responsible for oxygen supply and delivery
 |  |
| 1. Hospital elevation (for example: 1371m):
 |  |
| 1. How many beds are in the hospital (including any expected new beds)?
 |  |
| 1. How many operating rooms are there in the hospital?
 |  |
| 1. How does the hospital currently deliver oxygen to the bedside (wall-mounted outlets or individual cylinders)?
 |  |
| * 1. If outlets, how are they supplied? Cylinder manifold(s) or directly from existing PSA plant?
 |  |
| * + 1. If cylinder manifold, please list the number of cylinder manifolds as well as the number of cylinders per manifold (for example: 2-cylinder manifolds for surgery with 2x 5 cylinders, 1 cylinder manifold for emergency with 2x 2 cylinders)
 |  |
| * + 1. If there is an existing PSA plant, what is the size of the PSA (in m3/h)?
 |  |

1. **Future PSA Plant Information**

|  |  |
| --- | --- |
| Question | Response |
| 1. Does the hospital plan to connect the PSA plant to an existing piping network? If yes:
	1. What is the material of the existing pipe?
	2. Are there leaks or signs of corrosion present in the existing piping network?
 |  |
| 1. Does the hospital plan to install a new piping network?
 |  |
| 1. Does the hospital plan to fill cylinders for other health facilities?
 |  |
| 1. How many cylinders (including bedside, other health facilities, backup) does the hospital plan to fill per day?
 |  |
| 1. What is the size of the standard cylinder the hospital uses (given in water volume or liters of oxygen)?
 |  |

1. **Electrical Infrastructure**

|  |  |
| --- | --- |
| Question | Response |
| 1. Is the hospital connected to a local utility for electricity?
 |  |
| 1. Are there power outages, voltage fluctuations, or other instabilities?
 |  |
| 1. Is there an existing backup generator for the hospital?
 |  |

1. **Building Infrastructure**

|  |  |
| --- | --- |
| Question | Response |
| 1. Is there a location on hospital grounds where a new PSA plant building, or container, could be located? If yes, what are the approximate dimensions of the site?
 |  |
| 1. Is the identified location outside of areas prone to flooding?
 |  |
| 1. Is the identified location away from pedestrian traffic?
 |  |
| 1. Is the identified location accessible by truck?
 |  |
| 1. Can a crane access the identified location (necessary for delivery of containerized PSA plants)?
 |  |
| 1. Is the identified location at least 10m from open flames, generators, car exhausts, garbage, or any other air pollutants?
 |  |
| 1. Is there an existing concrete slab at the location? If yes, what are the dimensions? Is it covered or exposed to environmental risk?
 |  |
| 1. Is there a designated space for storage of cylinders?
2. If the above building infrastructure has not yet been constructed:
 |  |
| * 1. has it been budgeted?
 |  |
| * 1. who is the responsible entity or person?
 |  |
| * 1. who will be the project manager of this construction?
 |  |
| * 1. what is the timeline to completion of the required housing structure or concrete pad?
 |  |

1. **Human Resources**

|  |  |
| --- | --- |
| Question | Response |
| 1. Who will be responsible for the day-to-day maintenance of the PSA plant? Is this person located on-site at the hospital full-time and salaried or volunteer?
 |  |
| 1. What kind of training does the hospital technical staff in charge have regarding the maintenance of PSA plants?
 |  |
| 1. Do these on-site technical staff have access to hand tools commonly used for equipment maintenance?
 |  |
| 1. Does the staff have access to a handheld oxygen analyzer?
 |  |

1. **Equipment Specifications**

If the hospital has already identified the specifications for the new PSA plant, please list that information here:

|  |  |  |
| --- | --- | --- |
| **Component** | **Size** | **Not Yet Determined*****(Check box)*** |
| PSA Plant (Nm3/h) |  |  |
| Air Compressor (kW) |  |  |
| Booster Compressor (kW) |  |  |
| Size of Cylinder Filling Manifold |  |  |

If needed, follow the steps below to verify the PSA plant specifications.

**Steps for verification of Equipment Specifications**

The following calculations are preliminary sizing estimates. Other sizing recommendation tools exist, and the tool used here is intended to provide an estimate of required plant size.

Step 1: Oxygen Needs Estimate

Using the Table 13 recommendations from the [UK NHS Health Technical Memorandum (HTM)](#MedicalGasesMemorandum) on medical gas pipeline systems, the PSA plant can be sized based on bed counts. Follow the instructions below to estimate the Total Hospital Demand based on room and bed counts. The diversified flow is the total flow assumed to be used simultaneously in the hospital and is the measurement used to size PSA plants.

*Instructions: Fill in the counts for* ***rooms (nT)*** *in Column A. Input the number of rooms from Column A into the equation in Column B and note the solution in Column C. Then, sum the values in Column C to get the Total Operating Room Demand.*

|  |  |  |  |
| --- | --- | --- | --- |
|  | **A** | **B** | **C** |
| **Room Designation** | **Number of Rooms, nT** | **Diversified Flow Equation** | **Total Oxygen Flow, Q (lpm)** |
| Major Operating Room |  | Q = 100 + (nT – 1)10 |  |
| Minor Operating Room |  | Q = 100 + (nT – 1)10 |  |
| **Total Operating Room Demand** |  |

*Instructions: Fill in the counts for* ***beds (n)*** *in Column A. Input the number of beds from Column A into the equation in Column B and note the solution in Column C. Then, sum the values in Column C to get the Total Bed Demand.*

|  |  |  |  |
| --- | --- | --- | --- |
|  | **A** | **B** | **C** |
| **Room Designation** | **Number of Beds, n** | **Diversified Flow Equation**  | **Total Oxygen Flow, Q or Qw (lpm)** |
| Emergency Treatment Room |  | Q = 10 + [(n – 1)6/10] |  |
| Labor/Delivery/Maternity Room |  | Q = 10 + [(n – 1)6/4]  |  |
| Pre-Op/PACU |  | Q = 10 + [(n – 1)6/4]  |  |
| NICU |  | Q = 10 + (n – 1)6 |  |
| PICU |  | Q = 10 + [(n – 1)6]3/4 |  |
| General ICU |  | Q = 10 + [(n – 1)6]3/4 |  |
| High Dependency Unit (HDU) |  | Q = 10 + [(n – 1)6]3/4 |  |
| General Adult Patient Ward |  | Qw = 10 + [(n – 1)6/4] |  |
| General Pediatric Patient Ward |  | Qw = 10 + [(n – 1)6/4] |  |
| **Total Bed Demand** |  |

Add the Total Room and Bed Demands from the tables above to get the estimated Total Hospital Demand.

|  |  |
| --- | --- |
| Total Operating Room Demand (lpm) |  |
| Total Bed Demand (lpm) |  |
| **Total Hospital Demand (lpm)** |  |

If the hospital plans to fill cylinders for use in other health facilities, please fill in the section below to estimate oxygen demand for the cylinders. If the cylinders are measured in water volume, use Row A to enter that value and multiply by the factor in Row B to get a value for Row C. If the cylinders are measured with volume at pressure, enter that value directly into Row C and skip Rows A and B. If the hospital does not plan to fill cylinders, skip this section. If the hospital plans to fill cylinders for use in the rooms and beds captured in the previous section, skip this section.

|  |  |  |
| --- | --- | --- |
| A | Volume of Cylinders to Be Filled (water volume)*for example: 40L, 50L* |  |
| B | $$×$$ | 150 |
| C | Volume of Cylinders to Be Filled (at pressure)*for example: 6000L, 7200L* |  |
| D | Number of Cylinders to Be Filled per Day |  |
| E | Calculate Liters per Day: $Row C× Row D$ |  |
| F | Calculate Liters per Minute: $Row E÷ 24 hours ÷ 60 minutes$ |  |
|  | **Total Cylinder Demand (lpm)** |  |

Add the Total Hospital Demand and Total Cylinder Demand to get the Total Demand for the PSA plant. If the hospital has no cylinder demand, the Total Demand will be equal to the Total Hospital Demand.

|  |  |
| --- | --- |
| Total Hospital Demand (lpm) |  |
| Total Cylinder Demand (lpm) |  |
| **Total Demand (lpm)** |  |

Step 2: Compressor Estimate

The compressor pulls in ambient air and compresses it for use in the oxygen generator. Approximately 20% of ambient air is oxygen and PSA plants are generally 40% efficient. This means that about 8% of the air entering the compressor exits the PSA plant as medical oxygen. Using this factor and the Total Hospital Demand from Step 1, the minimum size of the compressor needed can be estimated. Note that the value calculated below is only an approximation to get a general idea of PSA plant specifications. **The values calculated should not be used to purchase equipment. The final equipment sizes must be determined by the manufacturer.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Total Demand (lpm)** |  | **Compressor Factor** |  | **Compressor Outlet Flow (lpm)** |
|  | $$÷$$ | 0.08 | = |  |

The compressor outlet flow can be used to estimate the required power for the compressor. The power factor used here is an average based on common types of rotary injected screw compressors. As such, the compressor power calculated here is only an estimate and should always be considered a minimum power requirement.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Compressor Outlet Flow (lpm)** |  | **Power Factor** |  | **Compressor Power\* (kW)** |
|  | $$÷$$ | 139 | = |  |

\*Note: If the elevation of the site is greater than 1000m, it is likely that the compressor will need to be upsized to account for changes in air density. Expect power requirements greater than what was just calculated if the site is higher than 1000m.

Step 3: Booster Compressor Estimate

If the PSA plant is filling cylinders, it will need a booster compressor. The power factor used here is an average based on data from the most common US and European booster compressor manufacturers. Refer to Step 1 and bring the Total Cylinder Demand value here:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Total Cylinder Demand (lpm)** |  | **Power Factor** |  | **Booster Power (kW)** |
|  | $$÷$$ | 40 | = |  |

Step 4: Generator Estimate

The generator needs to be sized for the power requirements of the compressor and the booster at start-up. The scaling factor in the table below is 2 and this assumes that the PSA plant will have a Variable Frequency Drive (VFD). It is generally recommended that a PSA plant include a VFD to minimize the power required to start the PSA plant. If the PSA plant at this hospital will not have a VFD, replace the scaling factor for the compressor and booster (currently 2) with 3.4. Follow the steps below to estimate a minimum generator size.

Pull the Compressor and Booster Power estimates into the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Component** | **Power (kW)** |  | **Scaling Factor\*** | **Start-up Power (kW)** |
| Compressor |  | $$×$$ | 2 |  |
| Booster |  | $$×$$ | 2 |  |
| Miscellaneous\* | 3 | $$×$$ | 1 |  |
| Total Start-up Power (kW) |  |
| Is this a duplex system? If it is possible that both machines can be started at the same time, multiply this value by 2. | $×$ 2 |
| **Total Start-up Power for Duplex System (kW)** |  |

*\*Miscellaneous power requirements include systems like lighting, air conditioning, and ventilation. Depending on the environment, the miscellaneous power requirements may be greater than the estimated 3kW used in this table.*

The Total Start-up Power (or Total Start-up Power for Duplex System, if relevant) is the minimum generator capacity. If the generator is not dedicated to the PSA plant, ensure that the Total Start-up Power and other loads combined do not exceed the generator capacity.

Step 5: Summary of Preliminary Equipment Specifications

Populate the table below to create a snapshot of the preliminary equipment specifications.

|  |  |
| --- | --- |
| Component | Size |
| PSA Plant (lpm) |  |
| PSA Plant (Nm3/h) \* |  |
| Air Compressor (kW) |  |
| Booster Compressor (kW) |  |
| Min. Generator (kW) |  |

\*Multiply lpm by 0.06 to get Nm3/h

**Additional Elements of PSA plant assurance and quality monitoring:**

1. Warranty: Details of warranty provided by the supplier of the PSA plant
* Verify that the PR understands the terms of the warranty, and what materials are covered and for what duration
1. Maintenance plan: Details of maintenance plan inclusive of the list of spare parts (storage and schedule of delivery)
* Verify that the PR is in contact with the party under contract to perform ongoing maintenance, and understands the terms of the maintenance contract
* Verify spare parts are stored in a safe and secure location
1. Training plans for capacity building of the designated human resources for operation and maintenance of the PSA oxygen plants
* Verify that the training provided by the plant installer is adequate or if additional training is needed for technical staff. If yes, what are those needs?

**Deliverable(s):**

The report should address each of the points listed under the scope of review/list of tasks above, as per the Global Fund request, and supplemented by other relevant information. It should include without limitation:

1. A detailed description and analysis of issues/risks identified. The LFA should comment on the context and root causes of the issues identified, providing background information as necessary and prioritise the list of issues in an executive summary according to their significance.
2. The LFA should review the budget for the above elements to identify any gaps in the budget that could pose a risk to full commissioning, maintenance, and warranty of the PSA plant.
3. Recommendations for addressing issues identified. Recommendations should be:
* Detailed – with all the relevant information included
* Specific and contextualised
* Time-bound
* Prioritized based on the level of risk
* Identifying the main entity responsible for implementation

**Required background reading**:

* Relevant Global Fund grant documents and PR program updates, national oxygen scale up plans, road maps and strategies, Oxygen Technical Working Group documents related to oxygen supply, distribution, and delivery,
* The PR’s PSA plant monitoring and QA plan, if applicable
* The relevant Global Fund’s guidance documents on Quality Monitoring and assurance of Oxygen equipment, PSA plants and standards in countries.

**Service Delivery**:

This review will be executed by the designated LFA Biomedical Engineering Expert (Oxygen)expert accountable for the technical content of this report. S/he can be supported by other LFA team members in the planning and during the verification. The LoE for this task, including report writing, depends on which elements of the ToR and the number and location of service delivery sites included in the review, as agreed between the Global Fund country team and the LFA.

If the review identifies clear evidence of fraud, the LFA should use the Global Fund Communication Protocol to inform the Global Fund Secretariat and the OIG to allow evidence collection and other issues relevant to a possible criminal investigation.

**References:**

WHO Foundations of medical oxygen systems February 2023 https://www.who.int/publications/i/item/WHO-2019-nCoV-Clinical-Oxygen-2023.1

DH Estates and Facilities Directorate. “Medical gases Health Technical Memorandum 02-01: Medical gas pipeline systems” May 2006. <https://www.england.nhs.uk/wp-content/uploads/2021/05/HTM_02-01_Part_A.pdf>