

## **HEAT AND MASS TRANSFER IN THE LONG RAINS: DOING ENGINEERING UNDER A MANGO TREE**

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**Abstract:** Academic engineering exists primarily as a monoculture. In common with agricultural monocultures, it has a genetic (inherited) uniformity across international boundaries and climatic zones; it demands continuous and expensive inputs (of equipment, staff- and laboratory- time) and is highly susceptible to drought and common diseases (staff shortages, curriculum revision . . .) A typical engineering degree is specialised, rarified, expensive – and often impractical and ill-suited to the demands made on it by societies struggling to take control of their own development.

In many practical situations, some basic engineering knowledge and understanding is all that is necessary to empower practitioners to take control of their own learning and investigations. Education “in the field” can give a major boost to students’ motivation and self-learning. Once they have grasped some fundamental principles in their area of concern, they can take their own measurements, draw their own conclusions, and devise effective, locally-applicable engineering solutions to the practical problems they confront.

Examples are cited from the author’s engagement with Knowledge Transfer Partnerships in Africa; but the principles are more widely applicable to non-specialist engineering teaching and possibly to short courses in industry.

*Keywords; self-learning, development, drying, energy efficiency*

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### **1. INTRODUCTION**

Engineering has become a reserved, professional discipline, and rightly so in many instances. Design and construction of big dams; of nuclear power plant; of offshore platforms, refineries and passenger aircraft are properly the province of highly qualified and certificated specialists. But the mystique that has come to surround engineering may also be an impediment to the active involvement of other scientifically- or technically-educated people in the solution of fundamental day-to-day problems. In countries where the pool of such educated and skilled manpower is small, all available resources need to be mobilised in support of national development goals. To do this, people with little or no engineering training need to be equipped with the intellectual tools and techniques to tackle basic problems as they occur (and to recognise where their knowledge is inadequate to the task) and the motivation to learn what they need to know. This is well illustrated

in the classic case of motor car maintenance – an important part of the upbringing of young men in many and diverse societies was/is the acquisition of skills of fault diagnosis and repair – usually by assisting their slightly older and more skilled peers. (Regrettably this particular skill acquisition has been eroded over the last two decades by the increasing prevalence of electronic ignition, computer diagnostics and non-repairable components).

This basic grasp of mechanical operation has propelled generations of young people into the study of engineering; and has endowed very many more with an appreciation of things mechanical. But increasingly, academic engineering has taken a very different path and has come to exist primarily as a monoculture: a uniform diet of basic principles and a set of remarkably similar edifices built on these. In common with agricultural monocultures, academic engineering exhibits a genetic (inherited) uniformity across international boundaries and climatic zones; it demands continuous and expensive inputs (of equipment, staff- and laboratory- time) and is highly susceptible to drought and common diseases (staff shortages, curriculum degeneracy. . .) A typical engineering degree is specialised, rarified and expensive (Salter 1995) – and this may often mean that it is impractical and ill-suited to the demands made on it by poorer societies and developing countries that are struggling to take control of their own development. But there are a variety of styles of learning, suited to different educational stages and objectives (Goldberger 1984, Beard & Wilson, 2002); and these can be deployed appropriately to meet a variety of educational needs.

In many practical situations, some basic engineering knowledge and understanding is all that is necessary to empower practitioners to take control of their own learning and investigations. But traditional classroom-based education doesn't imbue a "learning-by-doing" approach: passive- and rote-learning are the styles most usually adopted in the classroom. The challenge to develop and transmit engineering expertise that is inclusive, and accessible to individuals with only a modest educational attainment, is not often taken up. This has been particularly noted by respondents to the Harvard Africa Higher Education Student Survey Project (2008).

Education "in the field" can give a major boost to students' self-motivation and self-learning. Once workers – from a wide variety of educational backgrounds, and none – have grasped some fundamental principles in their area of concern, they can take their own measurements, draw their own conclusions, and devise effective, locally-applicable engineering solutions to the practical problems they confront. Two specific examples, both from Knowledge Transfer Partnerships in Africa, are described below, and an attempt is made to draw some more generally applicable conclusions. In each case a short, intensive, practical on-plant course was devised which enabled factory workers, ranging from Form 4 leavers to degree qualified engineers, to take control of their own learning, make and interpret appropriate measurements on plant, and design measures to reduce energy costs, improve product quality and boost output and profits.

## **2. AFRICAN KNOWLEDGE TRANSFER PARTNERSHIPS**

### *2.1 The African model*

"AKTPs" were instituted in four African countries: Nigeria, Ghana, Kenya and Uganda, in 2006, following the model of KTPs (formerly Teaching Company Schemes) long established in the UK. The African model has four elements:

1. Company identifies a significant issue/problem/opportunity requiring input of time and expertise to which the company may not have ready access. It commits to employing an appropriately qualified graduate as a KTP Associate (normally recently graduated; possibly with a Masters degree) for two years to work specifically on this. There is no commitment to continue the employment beyond this time.
2. KTP office identifies local academic staff who should be able to advise and contribute effectively to the project; they will be seconded by their University, and paid from KTP funds, for up to 1 day/week to work alongside, and supervise, the KTP Associate.
3. Advert placed, interviews held and Associate appointed.
4. Additional support is provided by local KTP officer who may engage an overseas expert to complement the supervisory team, and possibly arrange appropriate training for the Associate and others.

Funding for seconded academics and for the local and international Advisers has been provided through the British Council offices in Lagos, Accra, Nairobi and Kampala. These offices have also played a pivotal role in the provision of training for the Associates, in monitoring of work in progress (through a “Local management committee” for each project) and in the evaluation of outcomes (British Council).

### *2.2 Significance of training*

It will be evident that, for a project to be successful, there should be close cooperation between all the parties involved. Equally, if the impact is to extend beyond the initial 2-year project lifetime, then training should be extended to other company employees, with the active participation of local supervisors (“Knowledge Base” in KTP terminology). In the initial stages of AKTPs, “training” was rather narrowly defined as training the *Associate*; and as a newly-appointed Adviser I was asked to arrange 2 weeks of intensive laboratory training in the UK, implying 10 days of dedicated supervision/training time, plus time spent in preparation. The alternative would be to carry out training on-site, where other company employees could reap the benefits – and where the local academic staff could also become involved.

### *2.3 Development of a training model*

The requirements for such on-site training were assessed as being:

1. Accessible to staff from a variety of educational backgrounds
2. Practically based, to aid assimilation of theoretical concepts
3. Laboratory experimental measurements should complement those taken on plant
4. Participative; and arranged for small-group work
5. Challenging: participants have to tackle “open-ended” problems
6. Should help participants to “know what they don’t know” – and how to learn independently.

## **3. DRYING PROCESSES AND ENERGY USE**

### *3.1 Uganda Clays, Kajjansi, Uganda*

The first AKTP, (Case study A) at Uganda Clays, was aimed at identifying a replacement for (increasingly scarce and expensive) coffee husk as a furnace fuel. Key to this project was: how much energy is actually required in the process? If the energy required for processing clay products were used more efficiently, would the requirement for replacement fuel diminish – or

disappear altogether? Allied to this question is that of the energy requirement for predrying of clay products before firing: that is, the latent heat of evaporation of the moisture content of the formed products, coupled with the efficiency with which this energy is supplied. And again allied to this is the *rate* of drying achievable: what factors affect drying rates, and how may drying rates be improved without deleterious effects on the products? Thus appropriate on-plant training should enable participants to:

- determine rates of air-drying of clay products under measured conditions of temperature and humidity
- be able to use a psychrometric chart - we used the simplified version from Wikipedia (2007) - to determine the effect on drying rate of changing atmospheric conditions
- carry out mass and energy balances to establish the airflows required at different stages of drying
- measure heat losses and hence propose energy-saving measures
- produce maps of airflow/temperature/humidity in different regions of the plant
- establish the effectiveness of any energy-saving measures implemented
- hence perform a cost-benefit analysis for different energy-saving proposals
- assimilate new concepts in energy efficiency, psychrometry and drying as needed

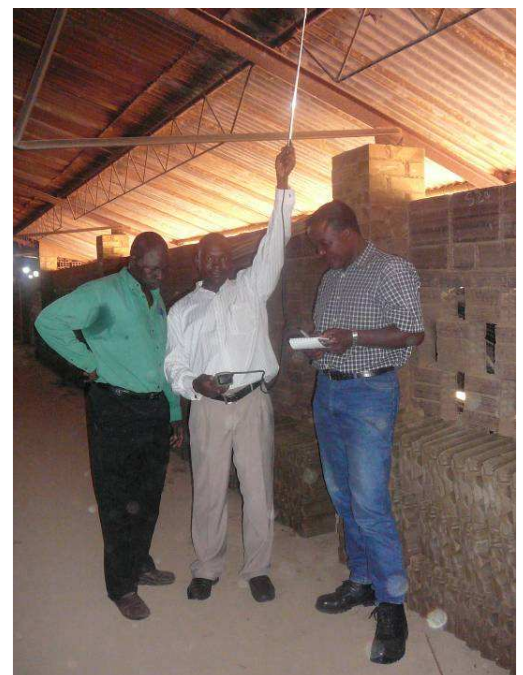
This “syllabus” had to be covered in three days, *and* produce sufficient results to demonstrate the effectiveness of systematic on-plant and in-lab measurements in improving drying and energy efficiency.

### 3.2 Course preparation

Local arrangements, including the manufacture of a laboratory tunnel dryer, (Figure 1) were in the hands of the Associate. My own preparation was based on a brief earlier visit; and I came equipped with an airflow/temperature/humidity meter and telescopic probe for on-plant measurements (Figure 2).



**Figure 1: locally-constructed tunnel dryer**



**Figure 2: using the airflow/temperature/humidity probe**

### 3.3 Course operation

The class composition was as described in Appendix 1. Given the limited possibilities for classroom teaching with so disparate a group, the carefully-prepared technical presentations had to be abandoned and the whole class took a tour of the plant. At each stop, a staff member associated with that part of the plant was asked to give a basic description of the processes being carried out and problems experienced; and all participants were encouraged to ask questions – moderated in such a way as to eliminate any embarrassment through being unable to answer on the spot. Thus within two hours the participants built up a catalogue of plant-related issues for study.

Back in the classroom, these issues set the agenda: participants decided what they “needed to know” in order to understand the drying processes and energy use on the plant; and determined how laboratory measurements taken under controlled conditions could be used to calculate drying rates. Thus armed, participants were divided into multi-ability groups and assigned tasks that they had identified during the walk-round. These included measuring, and proposing ways of improving, airflow distribution in predryers and “artificial dryers”; the effects of insulating hot-air ducts; and re-using exhaust air streams. Simple calculations and the use of psychrometric charts led to each group developing “solutions” that were then reported to, and discussed by, the whole workshop. Several innovations were made “on the hoof”: a cardboard-box model of one of the drying sheds was constructed to demonstrate how airflows might be redirected; groups adopted and refined the measurements and calculations made by others; a spreadsheet was developed for recording spatial data around the plant.

The principal outcome was the skills and enthusiasm acquired by participants over a short period, ensuring that energy efficiency remained on everyone’s agenda, and became a common currency of discussion on the plant – still being pursued actively on return visits made months later.

### 3.4 Adapting the experience

The second AKTP, (Case study B) at Mpanga Growers Tea Factory Limited, Fort Portal, Uganda had a number of strands: securing a sustainable supply of fuelwood from company plantations for raising steam used in the drying of tea; improving energy efficiencies across the board; and treating plant effluent. Again a key consideration was: *how much* energy is actually required in the process? If the steam generated and electricity used in tea processing were used more efficiently, what would the requirement then be for fuelwood and power?

### 3.5 A plant tour

The objectives of on-plant training of local staff were very similar to those at Uganda Clays; though the makeup of the staff group (Appendix 1) was yet more diverse. Building on the earlier experience, the 2-day course was designed from the outset to be plant-based, with concepts developed in the classroom as participants identified what they needed to know. In order to obtain the full involvement of staff – including those with no technical background at all – I used the “elephant and blindfold” method of asking each participant to describe “what do you see?” at each location. First stop – the woodpile (Figure 3), which provided a range of answers:

- Forester: *Eucalyptus grandis*
- Boilerman: 2 months’ supply of fuelwood
- Auditor: a lot of working capital
- AKTP Associate: a stack of fuel open to the rains
- Administrator: a pile that might fall on someone

- Myself: trees that are not photosynthesising!

Using this technique it was possible to establish the perceptions and level of understanding of participants, and hence pick tasks of differing degrees of complexity that would “stretch” participants appropriately.



**Figure 3: Fuelwood stacks at Mpanga Growers**

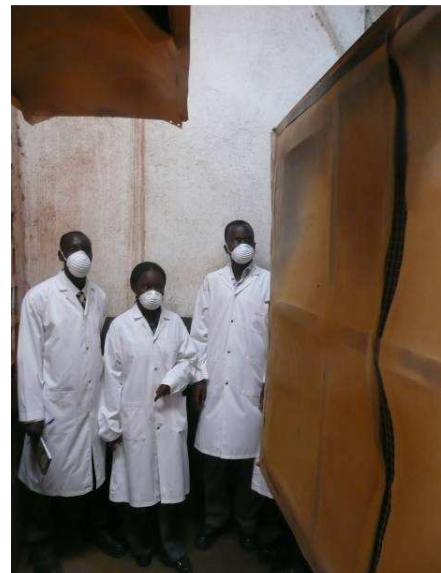


**Figure 4: Airflow and humidity measurements during “withering” of tea**

In the event, assigned tasks ranged from an attempt to characterise drying rates in the “withering” (predrying) process (Figure 4), to measuring power usage by drives on the fermentation section (Figure 5), and studying the effectiveness of the system that has been installed to recirculate hot (and humid!) exhaust gases back to the fluidised bed dryer (Figure 6).



**Figure 5: Drives in the fermentation section**



**Figure 6: Sampling the FB dryer exhaust!**

### 3.6 Implementing the findings

Each of these assignments gave rise to significant findings about plant operation and energy use:

- It was established that the withering process is extremely sensitive to the distribution of leaf on each withering trough; leading to the adoption of an operating procedure to be followed in manual spreading of the leaf.
- Replacement of oversized motors, together with rebalancing of phases, has led to a major reduction in power costs to the plant.
- Using the psychrometric chart, participants themselves discovered that recirculation of humid air prolonged the drying process and thus gave rise to an *increased* steam requirement per kg of tea! Performing these calculations gave participants the confidence to produce an embryonic design for an air-to-air heat exchanger for heat recovery.



**Figure 7: Explaining the findings of a plant survey, Mpanga Tea Growers.**



**Figure 8: Next step, hydropower!**

But again the most significant outcome has been the commitment of staff to make continuous improvements to energy efficiency on the plant, both for their own benefit and for that of the environment. Keighley (1997) makes specific reference to the lasting impact of such learning experiences, particularly with reference to outdoor, “classroom without walls” experiences (Pritchard, 2008). And following the termination of the AKTP, this work continues. A newly-appointed forester is designing a solar drying shed for harvested timber, and a volunteer “energy group” continues to monitor energy usage and propose energy-related operating improvements.

## 4. CONCLUSIONS

These two Case Studies demonstrate that basic engineering concepts may be assimilated and applied by workers who have little or no specialist engineering background. Short but intense workshop-style activities provide an appropriate context for learning new techniques and applying new insights. By following through their findings to the stage of making alterations to practices and processes on the plant, participants have been empowered to become innovators in their work.

Whilst in these examples the structure and continuity have been provided by AKTPs, the principal driver has been the companies' commitment to the process and to implementing required changes. In the circumstances, these workshops have proved to be both **effective** and an **efficient** use of the facilitators' time. Given the acute shortage of both engineering teachers and engineers in many African countries, this model offers an alternative route to engineering innovation that may be more widely applicable. The success of this mode of learning suggests it should be effective in undergraduate teaching, as a means of enabling students to cross the existing and well-fortified boundaries of specialist disciplines in engineering; and possibly also in industry-based short courses.

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### Appendix 1: Educational Backgrounds of Participants

#### At Uganda Clays, December 2007:

|            |                  |    |
|------------|------------------|----|
| Graduates: | Ceramics         | 1  |
|            | Elect Eng        | 1  |
|            | Civil Eng        | 1  |
|            | Energy Eng (MSc) | 1* |
| Diplomas:  | Civil Eng        | 1  |
|            | Ceramics         | 5  |

\*The AKTP Associate on this project

#### At Mpanga Growers, July 2009 & Feb 2010

|               |             |    |
|---------------|-------------|----|
| Graduates:    | Mech Eng    | 1  |
|               | Agric Eng   | 2* |
|               | Agriculture | 1  |
| Diplomas:     | Mech Eng    | 2  |
|               | Elec Eng    | 1  |
| Certificates: | Mech Eng    | 2  |
|               | Elec Eng    | 4  |

Plus internal auditor, admin, & factory asst.