

The object of this column is to enhance our readers' collections of interesting and novel problems in chemical engineering. Problems of the type that can be used to motivate the student by presenting a particular principle in class, or in a new light, or that can be assigned as a novel home problem, are requested, as well as those that are more traditional in nature and that elucidate difficult concepts. Manuscripts should not exceed 14 double-spaced pages and should be accompanied by the originals of any figures or photographs. Please submit them to Professor James O. Wilkes (e-mail: wilkes@umich.edu), Chemical Engineering Department, University of Michigan, Ann Arbor, MI 48109-2136.

## MURDER AT MISKATONIC

### *Passion, Intrigue, and Material Balances: A Play in Two Acts*

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#### *Dramatis Personae*

*Dr. Alexander Verawood:* Late and notable professor of engineering at the Miskatonic University of Arkham, Massachusetts.

*Dr. Xavier Verawood:* Alexander's younger brother.

*Richard Pendleton:* Alexander's personal assistant.

*Gabriella de Morcef:* Graduate student in the laboratory of Alexander.

*Thaddeus Hardcastle:* Powerful tycoon with ethically questionable business tactics.

*Aurora Simonova:* Alexander's mistress.

*Zelda Verawood:* Alexander's wife.

*Dr. Errol Curry:* Miskatonic engineering professor; colleague of Alexander.

*Tommy Benedict:* Custodian for the Miskatonic U. Chemistry and Engineering building.

#### I. THE SCENE

*"Thank you Pendleton. Just park here and we'll go in together; it's much too cold for you to wait in the car."*

*Dr. Xavier Verawood and Richard Pendleton climbed the stone steps of the Miskatonic University Chemistry and Engineering building together. After passing through the large wooden doors at the entrance, they approached the*



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entrance to the Research Level, where the secretary greeted them, making a note of their arrival in the log, like this: "Verawood, Xavier, and Pendleton, Richard: in 8:40 a.m., 21 Nov. 1932." The pair continued past the desk through the well-lit hall and descended to the basement. Halfway down the corridor Xavier opened the laboratory door of the great Dr. Alexander Verawood, his brother and the reason for his visit, and stepped in.

The room was dominated by a huge copper tank, taller than Xavier and polished to a bright orange luster. It was feeding from a collection of tanks that surrounded it as it brooded in the center of the room. From the top and sides of the vessel sprouted a multitude of thin pipes that stretched out like tendrils from a vast and carnivorous jungle plant. Each line snaked its way to one of many contraptions on sturdy tables arrayed upon the flagstones of the lab's floor, or to a wall rack where an amber-colored liquid was subjected to the gauntlet of a multitude of delicate glassware and shiny metal, which looked to Verawood like some kind of glittering alchemy.

The place smelled, strangely, like a bakery next door to an auto garage, and it resonated with a humming sound and a regular pulse like a slow heartbeat. Every now and then pressure was released from somewhere in great puffs, and a large mercury thermometer on the wall proclaimed a warm temperature of 77 °F. The pair was hailed by a voice from across the room.

Xavier turned to see a very small, dark-haired young woman whose large brown eyes stood out starkly against the white of her lab coat. She was wheeling a cart that bore several very large tanks to a corner of the room. Xavier and Pendleton helped her wrestle the tanks off the cart and onto the floor, where they were safely chained to the wall.

"Thank you," said the woman, brushing away a strand of black hair. "Those empty CO<sub>2</sub> tanks were left somehow over there next to the full ones. It's lucky they were still on the cart; they're very heavy and quite cumbersome to move around. Are you here to see anyone?"

Pendleton noticed that a few of the tanks in the lab were painted a brilliant blue and sported proud labels stating "The Blue Boy: 2 ft<sup>3</sup>, Guaranteed to 3000 psi." He remembered how the Professor, his employer, had once performed a certain favor for Warrington Industrial, the maker of the Blue Boy tank, and as a result found himself supplied with gas storage practically to his heart's content.

"Yes, ma'am, I'm Xavier Verawood, brother of the Professor, and I think you must already know Richard Pendleton, my brother's assistant. I arrived from Georgia last night."

"Of course, Dr. Verawood, your brother has told me about you. Aren't you a professor of Medieval and Renaissance Literature at Emory? My name is Gabriella de Morcef; I'm your brother's graduate student. What can I do for you?"

"Well, I did come here to see the Professor, but if it's not too much of an inconvenience I was rather hoping you could explain this cyclopean monstrosity to us," Xavier said, meaning the huge copper tank. "It looks terribly interesting, but I'm afraid I must humbly confess to a deplorable ignorance of chemistry and mathematics. And, please, call me Xavier: I still haven't quite gotten used to 'professor' or 'doctor'."

At this, Gabriella lit up. "Of course! Follow me to the incubator: This is where it all starts."

Intrigued, the two men allowed themselves to be swept in the wake of the tiny scientist, who led them to the monolithic bronze tank in the center of the room. Opening a slide in the outer casing of the incubator, Gabriella exposed a view cell through which a churning amber liquid could be seen swirling against the glass.

"It's fortunate that you arrived on a collection day; otherwise you wouldn't have seen the lab in all its splendor," she said.

"Now, this yellow liquid that you see through the glass is really an aqueous solution of yeast cells, kept at 37 °C in a mixture containing one part tryptone and other proteins—that's milk; well, more or less," she added as an aside, before ticking off the remaining ingredients. "One part NaCl, some glucose, and a dash of MgCl."

"These tanks that you see surrounding the incubator all contain O<sub>2</sub> or CO<sub>2</sub>. The CO<sub>2</sub> feed is part of a buffering system we use to keep our yeast cells producing their wonderful chemicals that this lab is dedicated to studying. Other reagents are mixed in with the solution, but they vary with the experiment that is being performed.

"As you must know, yeast cells are able to produce ethyl alcohol through fermentation; this is how beer is made. This lab is really quite like a plant, a brewery if you will, except we have found that we can coerce our little yeast cells to produce amazing hydrocarbons that can be modified for other uses, chiefly for fuel and industrial-lubricant applications. The trick is a combination of the proper choice of media and correct treatment of the cellular products. Essentially, we are using the machinery that already exists within the yeast cells to make our product! You can surely see how these very processes might drastically reduce our dependence on oil, and perhaps even eliminate it."

Here, Gabriella indicated the lines that radiated out from the incubator.

"On a collection day, the yeast solution, which by now contains our hydrocarbons of interest, is being sent off through this network of tubes to stations where various components alter the yeast feed. In the business, we call this a 'semi-batch' process. You can see on the wall there one of our distillation units; that particular component happens to be purifying the n-octane that the yeast cells have produced. The cells are be-

**“As for the methane/ethane waste, it’s piped into that Blue Boy over there on the bench. Every Friday after he makes dinner the Professor tops it up to 1500 psig, then when he wants, he opens up a little valve under his desk, allowing fuel to flow from that tank to his office.”**

ing lysed by a detergent, releasing the n-octane and forming a slurry of media, octane, and dead cell debris. From there, the mixture is heated and subjected to fractional distillation; thus, the octane is readily recovered. Each component that you see is doing essentially the same thing: It’s either autonomously synthesizing something or separating some important component of the virgin yeast feed that we might find to be a useful fuel or lubricant. It’s really a very simple process if you think of it in pieces.”

She smiled expectantly. Xavier tried not to let his eyes cross, but Pendleton simply nodded serenely. Xavier blushed, feeling like he had to ask something in order to avoid looking dim.

“Does nothing go to waste?” he blurted.

“Very astute, professor. Yes, the methane and ethane that we necessarily produce are useless. Stoichiometrically speaking, we produce about three times as much methane as we do ethane, and we used to just burn it all off to get rid of it.  $\text{CO}_2$  is also produced; the yeasts respire just as you and I do. That extra  $\text{CO}_2$ , however, is taken in tanks, on the cart that you helped me with, to photosynthetic algae that we grow on the roof in clear containers. There, the algae produce the sugars that we use in the yeast media in a  $\text{CO}_2$ -rich environment. We could, of course, be purchasing or using atmospheric  $\text{CO}_2$ , but why should we when we’re producing it right here in this room? Further, what we’re really trying to do is set up a working model of a plant that might someday operate on a near-closed cycle that couples the yeast/algae g-molecule exchange in order to supply us with cheap and virtually infinite fuels and lubricants. In the real plant, the  $\text{CO}_2$  would probably just be piped into the algae tanks automatically with the rest of the yeast products.

“As for the methane/ethane waste, it’s piped into that Blue Boy over there on the bench. Every Friday after he makes dinner the Professor tops it up to 1500 psig, then when he wants, he opens up a little valve under his desk, allowing fuel to flow from that tank to his office.

“There, he has a clever little burner of his own design that he managed to coax into operating at 90% efficiency. He’s even constructed a marvelous little carburetor that draws the perfect amount of oxygen into the flame chamber; I saw it heat a pint of water up to boiling in only three minutes when I had coffee with him last week. The secret is that the reactor geometry allows the fuel to combust virtually completely. I only hate how he uses the thing with the door closed, but he claims that the little bit of  $\text{CO}_2$  and water vapor that the burner produces is good for his office plants—one of his many eccentricities, I suppose.” She sighed. “He really is a brilliant

man, hates to waste anything at all, even though we do wind up having to dump what he can’t manage to reuse.”

“He’s been like that since childhood, Miss de Morcef, I can assure you,” said Xavier, glancing at the tank, whose gage now read 713 psig. “Is he in? I should very much like to see him; in fact, that’s the reason I came to Massachusetts. I stayed at his house last night, but you know how he gets so involved in his work that he winds up sleeping here.”

Gabriella nodded. “His new office is next door to the left. He took it because it’s close to the lab; it’s really not much more than a converted utility closet that was put into this basement when it was renovated. I would walk you there, but it’s never good to leave a high-pressure process unattended if one can help it, so you must forgive me. It was nice meeting you.”

The two men departed to Dr. Verawood’s office, which was out of the lab and next door, as they had been instructed. Xavier smelled the freshly painted walls and enjoyed the clomp-clomp of his shoes on the floor of the newly renovated hallway, while Pendleton silently noted the ventilation strips along the ceiling and floor g-molding. They were probably explosion-proof, he thought, and constantly running to prevent the buildup of dangerous gases in the basement.

The pair found a handsome hardwood door bearing the name “Dr. Alexander Verawood” on a golden strip. Both men noticed a strange smell that seemed to be leaking out from the large gap underneath the Professor’s door, no doubt put there in order to facilitate the slipping in of papers by students. Xavier knocked, but received no reply.

“Well Pendleton, he’s either engrossed in some great work or asleep. There’s no lock on this door; I’m sure he won’t mind if we go wake him up.”

“Of course he won’t mind, Dr. Verawood; he’s been very excited about your coming for two weeks now.”

Xavier turned the knob and pulled the door open. Immediately he uttered a choked gasp, cut short by the noxious rush of a malignant vapor, which smelled unmistakably like fuel gas. Pendleton coughed and sputtered as well, but retained the presence of mind to slap Xavier’s hand away from the light switch towards which it was creeping, thereby avoiding the chance of a quick spark followed by an unfortunate explosion.

“Ghastly smell, that. What’s the professor been...” he was stopped by the expression of horror on Xavier’s face. When Pendleton followed his gaze into the office, he saw what had upset the young professor.

There, on the floor of his own office, sprawled on the rug that he and Xavier had brought back from China, was the

great Dr. Alexander Verawood. He was cold, pale, and as dead as the flagstones he lay upon. Pendleton, falling to his knees from the onslaught of the horrible fumes and the sudden dull anguish that gnawed at his stomach, picked up the Professor's hand to check for a pulse. As he did so, Xavier noticed a pad of paper near the Professor's elbow bearing a single word:

**"MURDER."**

## II. THE SUSPECTS

"Monstrous!" cried Xavier that evening, in his late brother's study at the Verawood family mansion. He was reflecting upon the day's events, of how they had moved his brother's body to the Verawood family vault with the help of a trusted family physician. First, though, Xavier had had to fumble for the supply valve in order to shut off the gas that was pouring forth from his brother's unlit burner. Luckily, they had been able to get the body out of the building by placing it in a black bag on a cart and claiming that it was a delicate piece of equipment that someone in the physics building had requested to borrow for a while.

Faraday, the family physician (to whom the Professor's last note was not mentioned), had performed an autopsy that afternoon with the conclusion that Verawood had died of a heart attack. Maddeningly, no traces of poisons, cuts, bruises, or any other trauma had been found anywhere on or in the late Professor's mortal coil.

"How could this have happened? What callous fiend could be responsible for such a heinous act! Oh, Pendleton, what are we to do?"

"Courage, Doctor, courage, there's hope yet. We won't find your brother's assassin by useless raving, but by logic. I must admit though, it's rather puzzling. Perhaps we should involve the police?"

"Not on your life, Pendleton, not with that Hardcastle around. He probably owns every policeman in Massachusetts by now. The murdering thug! I'm sure it was him, he's been hounding my brother since the beginning of the yeast project, and we know he was there the weekend of the murder!" Xavier was shouting.

"That's a circumstantial accusation, and you know it. Sit down and I'll have Doris bring us some wine and whatever is left from that roast we ate last night."

Xavier moved from the window to the soft suede chair beside the bookshelf, where his father used to read Goethe on rainy nights.

"Do you think there's such thing as the perfect murder, Pendleton?" he asked, despondently looking out at the cold trees.

"No. You should know that. Nothing in the real world corresponds exactly to its ideal counterpart, though it can get

very close. Perfection only exists in mathematics. No, your brother's murderer made at least one mistake, maybe more, and it's up to us to find it and exploit it."

Doris arrived with the roast and a bottle of Burgundy. The two men moved to the heavy wooden table near the short wall of the room, which was still somewhat cluttered by Alexander's notes and calculations. After setting down the food and drink, Doris slipped out, noticing that the two were deeply engaged in conversation. Xavier took a bite of his dinner.

"That feels better, I think we can get on with it now," he said.

Pendleton nodded, as Xavier took a solemn breath, then continued. "Let's start at the beginning. We conferred with the secretary and checked the log, and decided that only six associates of my brother were present in the C & E building between the time he was seen at his evening class on Friday, and 9:00 Monday morning, when we found him."

Xavier found a scrap sheet of paper and a pen, and started writing.

"There were six," agreed Pendleton, "All of whom had some kind of connection or business with your brother."

This is what Xavier wrote down:

Suspects:

- 1) Thaddeus Hardcastle
- 2) Aurora Simonova
- 3) Zelda Verawood
- 4) Errol Curry
- 5) Tommy Benedict
- 6) Gabriella de Morcef

"Why don't we start with old Thaddeus?"

"Very well. We know from the secretary's log that he visited the Professor on Friday evening, but did he have a motive?"

"A motive!" shouted Xavier. "Of course he had a motive! This is the baron himself we're talking about! He's always in the papers, in and out of court for the convenient and 'accidental' deaths involving anyone opposed to his juggernaut of an oil empire. He's the only one not affected by this Depression we're in, Pendleton—everyone needs oil. Only now, he gets to pay his workers less for the same amount of labor: more people are willing to strain away on his derricks and rigs because no one can find jobs. Alex's yeasts would have ruined his entire industry eventually, and he visited my brother on the weekend he was murdered!"

Xavier was becoming heated, and Pendleton thought it best to push along the conversation.

"Friday evening, from 5 to 6. Ample time, I should think. Let's move on to Miss Simonova."

"Well, I won't pretend I don't know what she was, but I think you know more than I do about her," admitted Xavier. "Alexander hardly talked about her in his letters. Look, she

was at the building from 8:30 to 9:30 p.m. on Saturday. Tell me about Aurora, Pendleton.”

“She was rather the climbing type, I came to believe, though I don’t insult your brother’s taste. Unfortunately, despite my personal opinions (which reflect somewhat poorly on Miss Simonova’s character), I can’t say much about her save one important detail: she thought she and Alexander were legally married.”

“What?!” scoffed Xavier. “How is that possible?”

“Apparently she convinced the late Dr. Verawood to enter into some kind of contract with her that she believed legally tied the Verawood estate to her name. I think a lawyer of dubious qualifications and reputation was involved, but the

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contract will never stand up in a court of law. You can be certain that your brother knew this. It is, I think, rather akin to what is often called the ‘Vegas marriage.’ The point is I’m rather convinced that at the time of the murder she truly believed that she stood to inherit all that was your brother’s upon his demise. Ironic, isn’t it, that someone so adroit in the arena of social interaction should be so naïve when it comes to even the simplest of legal issues?”

Xavier didn’t ask how the old servant knew all this; he didn’t want to put Pendleton in the position of admitting to being a snoop. Instead, he said:

“Well, the next one is obvious. Alex told me in a letter that Zelda found out about Aurora and that the resulting tempest was cataclysmic.”

Pendleton shuddered, remembering. “That’s not too far from the mark. Mrs. Verawood has been getting increasingly agitated since that day in August, and the onset of winter has not lifted her spirits. Before she left here on Friday to stay at her parent’s estate, she had taken to brooding in her rooms. As you know, she’s always been one to hold in her feelings until they compel her to rashness, and when she left she seemed elated, as if her melancholy had lifted upon the making of some decision. And she was there, at the C & E building, from 8–9 p.m. on Sunday.”

Xavier hung his head. “I wish that poor Alex’s married life had worked out, but the truth is that they just weren’t made for each other. Naturally I’d like to cite Zelda’s intractably

spoiled attitude; I thought her a right termagant when Alex first met her. That’s probably prejudice, though, and my brother ought not to have behaved as he did in his private life.” He shrugged.

“Dr. Errol Curry,” said Pendleton.

“Errol grew up with us, as of course you remember. I can only recall the keen jealousy he felt for my brother, who was always his better in school, sports, and social relations. Alex treated him very magnanimously, as far as I know, but I think that that only seemed to infuriate Errol even more. Alex wrote to me last month and told me that the department, like everything else these days, is having serious financial problems and that one of the faculty would have to be cut. I’m sure Errol was afraid for his life. The poor man hasn’t done very well recently, or truthfully, at all, and perhaps he became rather desperate.”

“Though I do remember the jealous admiration with which he regarded your brother in childhood, I cannot lay claim to any knowledge about his professional situation. Still, we must include him in our consideration, for he was present at the building from 9 a.m. to 12 noon on Saturday, and from 9 a.m. to 8 p.m. on Friday. But who is this Tommy Benedict?”

“He’s the janitor,” replied Verawood, “who was scheduled to work this Saturday from 8 p.m. to 11 p.m. in the basement while no one was around. We know that the labs are locked all through the weekend, and he had one of the four keys. Curry and Miss de Morcef have the other two, I believe, tied as they are to the university. Alex, of course, had the fourth.

“That’s a sketchy connection,” continued Verawood, “But Benedict certainly warrants consideration on circumstance alone. Now, you said you had something to tell me about Gabriella.”

Pendleton steepled his hands and took on a rather ironic expression.

“My dear young Master Verawood, you won’t believe what I am about to tell you,” he began, “but our Miss Gabriella de Morcef has an acute case of hallucinogenic paranoia.”

“What?! What does that even mean? Could she have killed him?”

“Not only that, but she might not remember it.” Pendleton waited for the implications to sink in.

“The late Professor received a letter from her mother in southern France. She is, by the way, the progeny of rather noble French stock on her father’s side, but her mother was an Italian serving girl with whom her father became completely enamored during a trip to Italy in his youth. She turned out to be quite a graceful, intelligent, and virtuous woman who adapted to her new life without a hitch and delighted everyone around her, much like her daughter Gabriella.

“Your brother always raved about Gabriella’s unsurpassed creative and analytical prowess, how she saw to the heart

of even the most complex problems with a quick and sure dexterity that rivaled his own.

*“That letter from her mother, however, told of an incident that occurred while Gabriella and the family were vacationing in Nice one June. I think that Gabriella’s mother felt that Dr. Verawood should hear about it. The details are delicate and not pressingly relevant, but the end result was that Gabriella had an episode in which she felt that her life was in danger by unseen beings—beings, apparently, that gibbered to her in the sounds that a wind-flapped shingle made on the roof of her family’s seaside villa. Luckily her father found her before she could do any harm, for I’m given to understand that when he entered Gabriella’s room he found to his horror that her terrified little sister was physically restrained and in danger of receiving a mortal injury by Gabriella’s hand. Gabriella remembered nothing the next morning. Since, the young woman has been treated with medication, which has eliminated these violent episodes. What concerns me about this is that your brother told me once, in passing, that she feels her medicine curtails her higher and more subtle mental abilities, and that she does sometimes skip her pills.”*

*Xavier remembered the delicate, brilliant woman from the lab, so excited by her research and full of potential, and he felt a shiver well up.*

*“She was there on Friday from 9 a.m. to 5 p.m., and again Sunday evening from 5 p.m. to 12 midnight. When we asked her this afternoon, she said she spent Sunday in the library and Friday in the lab, and she doesn’t recall seeing the Professor after his evening lecture. Pendleton, what can we say about the fact that no one reported the Professor’s death at all? If Hardcastle was the one, then my poor brother lay in his office for the whole weekend while everyone else was coming in and out; surely someone must have seen the murder scene?”*

*“True,” replied Pendleton, thoughtfully. “True. I think that we must assume that every suspect that might have entered the building after the murder either 1) didn’t open the door of the Professor’s office or 2) did open the office door, but didn’t report what he or she found, and it’s not really too unlikely that one or the other situation actually occurred.*

*“The former is not so hard to believe with Curry, Gabriella, and Tommy, who are likely to have not sought the professor out and would not have missed his absence. We can be certain that Hardcastle saw the Professor alive on Friday, though he may have murdered him at that time. If Hardcastle is not the murderer, then he simply left when his audience had concluded.*

*“As for Aurora and Mrs. Verawood ... well ... we can’t assume that they entered the Professor’s office just because we know they were in the building. To have both not murdered the Professor and to have discovered and not reported the Professor’s demise seems unlikely; therefore we can guess*

*that if one of these women is a murderess then the other one probably didn’t enter the room.”*

*Pendleton had finished and sat quietly, musing. Xavier’s gaze turned again to the window, through which he looked forlornly at the dark, flowing Miskatonic under the night sky. The minutes ticked by on the grandfather clock that had stood in the study since his grandfather’s time. Sighing, Xavier looked back at Pendleton. Curiously, Pendleton was staring intently at the suspect list, which had been flipped over to reveal some of the late Professor’s old calculation pages, scribbled on the paper. “What is it, Pendleton?” whispered Xavier.*

*“I know a little something about logic and engineering after all my years in this house. Xavier, the murderer can only be one person: I know how to find out who killed Dr. Alexander Verawood, and we can do it without leaving the room.”*

## SOLUTION

First, it is necessary to determine the old Professor’s cause of death. We only know that there were no marks or trauma on his body, that he knew he was being murdered (hence the note), and that a doctor gave “heart attack” as the cause of death.

Now, we must think back to a few details. The Professor’s office is a converted utility closet located underground; probably having poor ventilation and no windows. Gabriella, the lab assistant, wheels a cartload of empty CO<sub>2</sub> tanks into place when the two sleuths enter the laboratory; they help her unload them to the floor. The door to the Professor’s office has no lock on it, but opens outward.

Now we think back to the empty CO<sub>2</sub> tanks that Gabriella was moving. The were too large to move by hand and therefore unlikely to be misplaced by chance, which should set us thinking that CO<sub>2</sub>, in very large quantities and in a small space, is as deadly as any poison.

The scene could have played out something like this: the Professor, minutes before he was killed, was cooking his evening meal on the little burner. Feeling a little hot under the collar, he gets up to stretch his legs, only to find that his shortness of breath gets worse. After a few minutes, he feels a pain in his chest and, desiring of fresh air, moves to his door, turns the handle, and pushes, only to find it blocked! Wondering what the obstruction could be, the Professor must have kept pushing with increasing worry as his head began to swim with lack of air. Sinking to the floor, he must have seen or heard the CO<sub>2</sub> being pumped into his office, decreasing the oxygen content of each of his breaths, and must have realized, at that moment, that his life was in danger. Before blacking out, he had time to leave his last note.

It was seemingly the perfect crime: no evidence, no fingerprints, no sign of a struggle, no need for the murderer to even enter the room. However, there was one more thing the murderer didn’t count on.

When the oxygen concentration of the room dropped, the Professor's life was not the only thing to snuff out! Indeed, the burner's pilot light could no longer continue to burn, but extinguished, allowing pure fuel gas to gush into the room. This is what Xavier and Pendleton smelled, and was why they didn't notice how thin the air was, for they were already holding their breath.

Now, the fuel gas was comprised of a 3:1 mol methane : mol ethane mixture and stored in a tank with a capacity of 2 ft<sup>3</sup> (56.63 L). Making the reasonable assumption that the Professor's basement office is at room temperature (77 °F, 25 °C) and 1 atm, we use Yaw's Chemical Properties Handbook to calculate the heat of combustion at 958.9 kJ/g-mol, making the assumption that the water product of combustion is in the vapor phase.

Gabriella mentions that the burner is 90% efficient and heats one pint (0.473 L) water to boiling in 3 min. Therefore, the flow rate of fuel into the burner must be 0.0574 g-mol/min, assuming everything at roughly STP, assuming that the heat capacity of water is a constant 4.187 kJ/kg\*K, and assuming that the density of water at 25 °C is 1 kg/L.

We also know that the 2 ft<sup>3</sup> tank was filled up to 1,500 psig

(10,440 kPa abs) before the Professor started using it, and that it was at 713 psig (5,020 kPa abs) at 9:00 a.m. on Monday. So, we have only to find how long the fuel had been escaping, then count backward to find out when the flame went out.

That's easy: using the Ideal Gas Law at the lab temp, which we know is 25 °C, we find that the difference between the two pressures of the tank corresponds to a loss of about 124 g-mol fuel gas. Now, dividing 124 g-mol by 0.0574 g-mol/min tells us that the fuel had been escaping from the burner for about 36 hours (2,160 min).

Counting backward from 9:00 a.m. on Monday, that means that the fuel began escaping at 9:00 p.m. on Saturday. There were two people present in the building at that time: Tommy Benedict and Aurora Simonova, but only Tommy had the keys to the lab (which is locked on the weekends) to get to the CO<sub>2</sub> tanks!

It turns out that the Professor, to supplement his skimpy funds, was running a distillery as a part of his yeast experiments in the basement. This, of course, was a risky occupation during Prohibition, and so Tommy, who worked for a local mob boss, was persuaded to eliminate the competition. □